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TERRESTRIAL MAGNETISM

AND

ATMOSPHERIC ELECTRICITY

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AN INTERNATIONAL QUARTERLY JOURNAL

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TERRESTRIAL MAGNETISM
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ON THE VARIATIONS OF COSMIC RADIATION DURING MAGNETIC STORMS

By THOMAS H. JOHNSON

Abstract—The experimental values of the geomagnetic cosmic-ray effects have been used in calculating the change of cosmic-ray intensity during a magnetic storm on the assumption that the magnetic disturbance can be regarded as a variation of the Earth's magnetic moment. The change in moment found necessary to produce the observed variations of cosmic-ray intensity during the storm of April 1937 is of the order 150 times greater than any value simply reconcilable with the magnetic disturbances recorded.

Correlations between variations in cosmic-ray intensity and magnetic disturbances have been cited by several investigators. Corlin[1] studied the cosmic-ray intensity, J, at Abisko, in northern Sweden, in 1929 and 1930. From 27 magnetic storms he reported an average increase of intensity during the period of weakened horizontal field-strength H of approximate magnitude $\mathrm{d}J/J \approx -\mathrm{d}H/H$, although there were wide departures from this relation in the individual cases. In 1933 Messerschmidt[2] reported a decrease of 1.3 per cent in cosmic-ray intensity during a nine-day disturbance in which the horizontal intensity dropped 0.1 per cent. In the same year Broxon, Merideth, and Strait[3] found an apparently significant correlation between magnetic and cosmic-ray character-numbers. Steinmaurer and Graziadei[4], from recordings on the Hafelekar, reported 17 magnetic storms out of a total of 24 in which the cosmic radiation decreased with the average intensity for all storms for the ten hours following the onset 0.3 per cent less than the average of the ten hours preceding the impetus; only the magnetic character-numbers of the storm-days were recorded, but there was no close correlation indicated between the magnitude of the cosmic-ray variation and the intensity of the magnetic disturbance.

During the large magnetic storm of April 1937 Forbush[5] and Hess and Demmelmair[6] have reported significant decreases of cosmic-ray intensity at Cheltenham, at Huancayo, and on the Hafelekar. Preliminary reports of similar variations have been communicated to the Department of Terrestrial Magnetism of the Carnegie Institution from Mexico and New Zealand. The changes in cosmic-ray intensity were apparently world-wide in character and at the three stations first named the lowest daily mean of cosmic-ray intensity was about four per cent

[1] A Corlin, Lund Obs. Cir., No. 1 (1931).

[2] W. Messerschmidt, Zs. Physik, **85**, 332-335 (1933).

[3] J. W. Broxon, G. T. Merideth, and L. Strait, Phys. Rev., **44**, 253-257 (1933); J. W. Broxon, Terr. Mag., **39**, 121-125 (1934).

[4] R. Steinmaurer and H. Graziadei, Berlin, SitzBer. Ak. Wiss., **22**, 672-685 (1933).

[5] S. E. Forbush, Phys. Rev., **51**, 1108-1109 (1937).

[6] V. F. Hess and A. Demmelmair, Nature, **140**, 316-317 (1937).

less than the mean of the 36 hours preceding the impetus of the first magnetic disturbance. For the corresponding times there was a change in horizontal magnetic field of 0.4 per cent so that for this particular storm

$$\mathrm{d}J/J \approx 10\mathrm{d}H/H \qquad (1)$$

On the basis of the Störmer-Lemaître-Vallarta theory of the geomagnetic cosmic-ray effects the variation of the cosmic-ray intensity during a magnetic disturbance can be calculated if it is assumed that the disturbance can be represented by a variation in the Earth's magnetic moment. The theory defines the intensity at latitude λ, zenith-angle ξ, and azimuth ϕ, produced by the positively and negatively charged components of the primary radiation, by means of the two integrals

$$j=\int_{V_0^+}^{\infty} j_v^+\,\mathrm{d}V+\int_{V_0^-}^{\infty} j_v^-\,\mathrm{d}V \qquad (2)$$

extending over the energy-spectra, j_v^+ and j_v^- from the critical energies V_c^+ and V_c^- to infinity. These critical energies are each defined in terms of the Earth's magnetic moment M and its radius a by relations which, in the case of singly charged particles having energy which is large compared with the rest mass energy, converge to

$$V_c = 300\, M\, r_c^{\pm 2}/a^2 \text{ electron-volts} \qquad (3)$$

where r_c^+ and r_c^- are purely mathematical functions of the latitude and direction. For a given latitude r_c^+ for one direction is equal to r_c^- for another direction symmetrical to the first direction with respect to the meridian-plane. At the zenith we thus have the following relations:

$$r_c^+ = r_c^- \qquad (4)$$

$$\mathrm{d}r_c^+/\mathrm{d}\xi = -\mathrm{d}r_c^-/\mathrm{d}\xi \quad ;\ \xi=0 \qquad (5)$$

where it is understood that the variation of ξ is taken in the east-west vertical plane. We will consider ξ as increasing towards the east. From (2) the variation of the unidirectional intensity j with respect to any one of the geomagnetic variables x is given by

$$\mathrm{d}j/\mathrm{d}x = -j_v^+(V_c^+)\,\mathrm{d}V_c^+/\mathrm{d}x - j_v^-(V_c^-)\mathrm{d}V_c^-/\mathrm{d}x \qquad (6)$$

There are five relations of the type (6), one for each of the five geomagnetic variables λ, ϕ, ξ, M, and a, but the relation involving ϕ becomes trivial at the zenith. Combining the remaining four relations together in pairs, and writing r_c in place of r_c^+ and α for the ratio $(j_v^+ + j_v^-)/(j_v^+ - j_v^-)$ the following six relations, referring to the zenith intensity j, are easily derived.

$$M\mathrm{d}j/j\mathrm{d}M = r_c(\mathrm{d}j/j\mathrm{d}\lambda)/2(\mathrm{d}r_c/\mathrm{d}\lambda) \qquad (7)$$

$$M\mathrm{d}j/j\mathrm{d}M = \alpha r_c(\mathrm{d}j/j\mathrm{d}\xi)/2(\mathrm{d}r_c/\mathrm{d}\xi) \qquad (8)$$

$$M\mathrm{d}j/j\mathrm{d}M = -(a\mathrm{d}j/j\mathrm{d}a)/2 \qquad (9)$$

$$\alpha = (\mathrm{d}j/j\mathrm{d}\lambda)\ (\mathrm{d}r_c/\mathrm{d}\xi)/(\mathrm{d}j/j\mathrm{d}\xi)\ (\mathrm{d}r_c/\mathrm{d}\lambda) \qquad (10)$$

$$\alpha = -(a\mathrm{d}j/j\mathrm{d}a)\ (\mathrm{d}r_c/\mathrm{d}\xi)/r_c(\mathrm{d}j/j\mathrm{d}\xi) \qquad (11)$$

$$a\mathrm{d}j/j\mathrm{d}a = -r_c(\mathrm{d}j/j\mathrm{d}\lambda)/(\mathrm{d}r_c/\mathrm{d}\lambda) \qquad (12)$$

Four of these relations are independent.

The present interest in these relations is the calculation of the coefficient (Mdj/jdM). In equation (7) it is related to the latitude-effect while equation (8) expresses it in terms of the asymmetry[7]. Experimental values for both of these effects are available. However the ratio of the two effects are required in equation (10) for the determination of the unknown α occurring in equation (8), so that these two methods of determining (Mdj/jdM) are not independent. If the longitude-effect at the equator were entirely due to the variation of a, equation (9) would constitute an independent determination of (Mdj/jdM) and equation (11) an independent determination of α, but there seems to be more to the longitude-effect than can be accounted for by the eccentricity of the Earth's magnetic center, and the experimental values of the longitude-effect agree only in order of magnitude with the "a-effect" calculated from the latitude-effect by equation (12), as may be seen by comparing lines h and j of Table 1.

TABLE 1—*Summary of quantities involved in equation (7) to (12)*

Line	Quantity and reference	Geomagnetic latitude			
		0°	10°	20°	30°
a	r_c, Lemaître and Vallarta	0.500	0.490	0.470	0.419
b	($dr_c/d\lambda$) per degree, Lemaître and Vallarta	0	−0.0015	−0.0035	−0.0075
c	($dr_c/d\xi$) per degree, Lemaître and Vallarta	0.0022	0.0021	0.00178	0.00126
d	($dJ/Jd\lambda$) per degree, Compton and Turner	0	0.0011	0.0016	0.0037
e	($dj/jd\lambda$) per degree, Gross reduction	0	0.0019	0.0028	0.0065
f	($dj/jd\lambda$) per degree, Johnson and Read	−0.001	0.00	0.0037	0.0054
g	($dj/jd\xi$) per degree, Johnson	−0.0017	−0.0015[a]	−0.0013	−0.0009
h	(adj/jda), Millikan and Neher, Clay, and Compton	1.3	....	....	....
j	(adj/jda), eq. (12) and line (*e*)	0.6[a, b]	0.61[b]	0.37	0.36
k	α, eq. (10) and lines (*e*) and (*g*)	....	1.7	1.07	1.19
l	α, eq. (11) and lines (*g*) and (*j*)	1.5	1.7	1.07	1.19
m	(Mdj/jdM), eq. (7) and line (*e*) or eq. (9) and line (*j*)	−0.32[b]	−0.31[b]	−0.19	−0.18
n	(Mdj/jdM), eq. (8) and line (*g*)	−0.19	−0.19	−0.17	−0.15

[a]Interpolated or extrapolated.

[b]The high values for latitudes 0° and 10° in lines *j* and *m* result from the particular way Compton and Turner have drawn their curve; values in close agreement with those of the higher latitude would also be consistent with their data.

Values of the various quantities involved in relations (7) to (12) are listed in Table 1. Lemaître and Vallarta[8] have computed r_c and its derivatives, listed in lines (*a*), (*b*), and (*c*). Line (*d*) gives the latitude-effect for the total radiation J as determined from the slope of the curve in Figure 12 of the paper by Compton and Turner[9] which gives the latitude-effect corrected for external temperature on the Pacific Ocean. Line (*e*) contains the latitude-effect for the vertical radiation derived from line (*d*) by a Gross [10] reduction. Gross' equation may be written

$$j = sJ \tag{13}$$

where $s = 1 - hdJ/Jdh$ and is a quantity which also varies with the latitude or with any other of the geomagnetic variables. From Figure 4

[7]T. H. Johnson, Phys. Rev., **48**, 287-301 (1935).

[8]G. Lemaître and M. S. Vallarta, Phys. Rev., **50**, 493-504 (1936).

[9]A. H. Compton and R. N. Turner, Phys. Rev., **52**, 799-814 (1937).

[10]B. Gross, Zs. Physik, **83**, 214-221 (1937).

of Compton's "Geographic study of cosmic rays"[11], s has been determined for the equator and for high latitudes. For purposes of interpolation it is reasonable to assume that s is a function of J and can be expressed by

$$\log s = 0.76 \log J + \text{constant} \tag{14}$$

where the constant 0.76 had been determined from the initial slopes of Compton's curves of intensity versus elevation. Substitution in (13) gives

$$\mathrm{d}j/j\mathrm{d}x = 1.76\ \mathrm{d}J/J\mathrm{d}x \tag{15}$$

where x stands for any one of the geomagnetic variables. Although a reduction of this type is logically untenable in the equatorial belt where the radiation is asymmetrically distributed in azimuth, the error introduced by its application is probably insignificant and as a matter of fact the total variation of intensity with latitude of the vertical intensity given by (15) agrees satisfactorily with the experiments in which latitude-effect is measured with vertical coincidence-counters[12]. The differential latitude-effects from the coincidence-counter experiments are listed in line (f). The incidental discrepancies between lines (e) and (f) are doubtless caused by magnetic anomalies along the route of the counter-apparatus. In line (g) the quantity ($\mathrm{d}j/j\mathrm{d}\xi$) has been determined from the initial slope of the curves representing asymmetry versus zenith-angle[7]. In line (h) is the value of the coefficient $a(\mathrm{d}j/j\mathrm{d}a)$ calculated from the longitude-effect as measured by Millikin and Neher, Clay, and Compton. These results have been conveniently compiled by Vallarta[13]; the value given has been calculated by taking the maximum variation of the intensity along the equator and dividing by the maximum variation in a. This disregards a difference of about 90° in the positions of the two minima, and the result is two or three times larger than the a-effect predicted from the latitude-effect listed in line (j). Neither the difference in magnitude nor the difference in positions of the minima between the observed and predicted longitude-effect have been satisfactorily interpreted.

The values of α, listed in lines (k) and (l) of Table 1 fall in the range from 1 to 1.5, confirming the preponderance of positives in the primary radiation previously reported[7]. A probable value of the magnetic-moment effect is

$$M\mathrm{d}j/j\mathrm{d}M = -0.2 \tag{16}$$

and Table 1 shows that it is nearly independent of latitude up to the critical latitude where it, along with other geomagnetic effects, must disappear.

If magnetic variations were due to changes in the internal magnetization of the Earth the change in moment during a storm could be determined unambiguously from the variations in the surface-field, but these measurements do not suffice when the variations are produced by external currents unless some assumption is made regarding the location of those currents. If it is assumed, as suggested by Chapman[14], that the

[11] A. H. Compton, Phys. Rev., **43**, 387-403 (1933).

[12] T. H. Johnson and D. N. Read, Phys. Rev., **51**, 557-564 (1937).

[13] M. S. Vallarta, Phys. Rev., **47**, 647-651 (1935).

[14] S. Chapman, Nature, **140**, 423-424 (1937).

external storm-currents are distributed over a sphere with current-intensity proportional to the cosine of the latitude, then the combined effects of the primary currents and the currents induced in the Earth upon the field at the Earth's surface, $r=a$, is given by

$$dM/dH = -(1/3)\,(2a'^3 - a^3) \qquad (17)$$

where dM is the change in the moment of a hypothetical dipole situated at the Earth's center which would produce the same change in the field external to the currents as that which is produced by those currents. If the currents are in the upper atmosphere then $a'=a$ and (15) reduces to

$$dM/dH = -1/3a^3 \qquad (18)$$

If (16) is combined with (1) the variation of cosmic-ray intensity during the storm of April 1937 leads to the result

$$dM/dH = -50M/H = -50a^3 \qquad (19)$$

The assumption underlying (19) (that the field traversed by the cosmic rays is that of a dipole at the Earth's center) is valid if the disturbance-currents are in the upper atmosphere but the effect, represented by (1) and (19) is 150 times more than can be reconciled with this assumption as represented by (18). It would be necessary to assume that $a'=4a$ if (17) is to correspond numerically with the experimental result (19), but with any such value of a' the underlying assumption of a dipole field breaks down and, as a matter of simple reasoning, one would have to expect an increase, rather than a decrease, of cosmic-ray intensity. The effect of the current-sheet is to weaken the field inside of itself and to strengthen the field outside and, since practically all of the deflection which acts to limit the allowed cone of cosmic rays takes place within the last few thousand miles, a weakening of the field in this region would allow cosmic rays to reach the Earth with less energy than the limit imposed by the field in the absence of the disturbance-currents. An exact calculation of the orbits in the disturbed field is needed to predict the effect with certainty, but the cathode-ray experiments of Brüche[15] indicate that the above interpretation is qualitatively correct.

An estimate of the maximum value of a' for which a decrease of cosmic-ray intensity could be expected as a result of the current-sheet may be obtained from the condition that the integral of the magnetic field along the disturbed orbit must be greater than the corresponding integral along the undisturbed orbit. The maximum value of a' is obtained by applying this condition to a radial orbit and this leads to

$$a'_{max} = 3a/2 \text{ and } dM/dH = -(23/12)\,a^3 \qquad (20)$$

Even in this case a considerable portion of the orbit would lie in a weakened field and taking this fact into consideration in the equations of the orbits would lead to a smaller absolute value of (Mdj/jdM) than given by (16) and a larger discrepancy between (19) and the result derived from (17). These considerations only make matters worse, and it is

[15]E. Brüche, Physik. Zs., 31, 1011-1015 (1930).

concluded that the effect of the storm of April 1937 upon the cosmic rays was at least 150 times more than can be accounted for by an increased bending of rays of cosmic origin in any disturbance-field reconcilable with the surface-measurements of the magnetic variations.

Since the geomagnetic effects constitute the most direct evidence that the rays are of cosmic origin it is a matter of fundamental concern that some satisfactory explanation be found for the storm-effect. The next step which suggests itself is the determination of the storm-effect at high latitudes. If it exists above the critical latitude (45°) as is already suggested by the experiments at Cheltenham and on the Hafelekar, as well as by the large effects in the opposite direction reported by Corlin in northern Sweden, then the explanation cannot be of a geomagnetic nature in the usual sense of the expression. The lack of consistency between the coefficients ($H\mathrm{d}j/j\mathrm{d}H$) reported for different storms would also indicate that some other effect is present. Possibly a related phenomenon is the diurnal variation of cosmic-ray intensity. Gunn[16] has already suggested a connection between this effect and the diurnal variation of the Earth's field; and the experimental values[17] of the 24-hour wave of cosmic-ray intensity together with the amplitude of the magnetic diurnal variations[18] result in a ratio ($H\mathrm{d}j/j\mathrm{d}H$) of somewhat the same order although significantly lower that that found from the storm of April 1937. It is well known that the storm and the diurnal disturbance-fields are of an entirely different character so that a comparison of the two effects would have no simple significance in view of a purely magnetic interpretation, but since a magnetic interpretation is impossible the comparison may be of some significance.

Finally it is a pleasure to acknowledge the cooperation of Messrs. J. A. Fleming, S. E. Forbush, E. A. Johnson, and A. G. McNish of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, who, through their discussion, have contributed much to the clarification of issues here presented.

[16] R. Gunn, Phys. Rev., **41**, 683 (1932).

[17] V. F. Hess and R. Steinmaurer, Berl. Ber. XV (1933); S. E. Forbush, Terr. Mag., **42**, 1-16 (1937); V. F. Hess and W. S. Pforte, Zs. Physik, **71**, 171-178 (1931); J. F. Thompson, Phys. Rev., **52**, 140-141 (1937).

[18] E. O. Hulburt, Rev. Mod. Phys., **9**, 44-68 (1937).

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RELATIONS BETWEEN TERRESTRIAL MAGNETISM AND COSMIC-RAY INTENSITY

By Victor F. Hess, A. Demmelmair, and R. Steinmaurer*

Abstract—Certain relations between the variations of the Earth's horizontal magnetic force H and of the observed cosmic-ray ionization J have been found in the continuous registrations of the cosmic-ray ionization on the Hafelekar, 2300 meters above sea-level (near Innsbruck, Austria) during the year 1936-37 as follows:

(1) A positive magnetic effect, ME_1, is indicated during magnetic storms with increase of J associated with increase of H and *vice versa*. A similar effect has been noticed rather often also in the daily mean values of J and H during magnetically undisturbed days. ME_1 amounts to $+0.57$ per mille of the cosmic-ray ionization for an increase of the horizontal force by one γ (0.00001 gauss).

(2) The analysis of the daily mean values for one year discloses a second effect, ME_2, of opposite sign (increase of H accompanied by decrease of J) and smaller than ME_1. ME_2, for the average of the year 1936-37, is about -0.20 per mille per γ.

(3) A similar negative magnetic effect, ME_3, is found from the strong correlation between the diurnal variation of H and J; $ME_3=-0.2$ per mille per γ.

(4) Another negative effect, ME_4, can be derived from the anti-parallel variations of the monthly means of H and J (seasonal curves); $ME_4=-1$ per mille per γ.

The three first-mentioned effects can be explained qualitatively by adopting the hypothesis of the electronic ring-currents in the outer space around the globe. The seasonal effect is not yet explained and it seems possible that its connection with terrestrial magnetism is accidental, in spite of the strong correlation.

Ever since the discovery of the variation of the cosmic-ray intensity with latitude by J. Clay, various observers have tried to find a relation between the fluctuations of the intensity of the Earth's magnetic field and the variations of the cosmic-ray intensity, after reduction to normal barometric pressure.

Ross Gunn[1] suggested that the diurnal variation of the Earth's magnetic field might cause the small diurnal variation of the cosmic-ray ionization according to local time, the existence of which has been established beyond doubt by one of the writers and his collaborators in Innsbruck (Austria) and on the Hafelekar (2300 meters above sea-level), and by other observers within the last few years[2].

J. Barnothy and M. Forró[3] found from counter coincidence-observations that the daily variations of the vertical component of the cosmic radiation seems to be caused mainly by the regular diurnal variation of the Earth's magnetic field which acts on the primary cosmic corpuscles even before they enter the atmosphere. On the average an increase of the magnetic horizontal intensity by one γ ($1\gamma=0.00001$ gauss) caused a decrease of from 0.056 to 0.070 per cent of the cosmic-ray intensity (number of coincidences).

Another way of testing the relationship in question is to investigate the non-periodic fluctuations of the daily mean values of the cosmic-ray ionization from day to day ("variations of the second kind"). This was first done by W. Messerschmidt[4] who also found a marked negative correlation in a three-month series of observations, carried out at Halle (Germany) by means of the large Hoffmann apparatus. A decrease of the magnetic horizontal force seemed to be accompanied by an increase of the ionization and *vice versa*.

*Communication No. 3 (News Series) of the Physical Institute, University of Graz, Austria.

[1]R. Gunn, Phys. Rev., **41**, 683 (1932).

[2]V. F. Hess and H. Graziadei, Terr. Mag., **41**, 9-14 (1936); V. F. Hess, H. Graziadei, and R. Steinmaurer, Wien, SitzBer. Ak. Wiss., IIa, **143**, 313-334 (1934); S. E. Forbush, Terr. Mag., **42**, 1-16 (1937); A. Demmelmair, Wien, SitzBer. Ak. Wiss, IIa, **146** (1937).

[3]J. Barnothy and M. Forró, Zs. Physik, **100**, 742-753, and **104**, 534-539 (1936).

[4]W. Messerschmidt, Zs. Physik, **85**, 332-336 (1933).

Not quite concordant results were obtained by the analysis of the observations on the Hafelekar, near Innsbruck, in 1933 (eleven months) by one of the writers and W. Illing[5] who declared that they were unable to get unambiguous evidence of a connection between the variations of the horizontal force and the variations of the daily means of cosmic-ray ionization; the latter was registered in a Steinke standard apparatus shielded with lead (10 cm thick). There were even series of days when an increase of the cosmic-ray ionization was accompanied by an increase of the magnetic horizontal force. A statistical analysis gave, on the whole, a small negative correlation of $r = 0.12$ (10 cm of lead on all sides) and -0.28 with no lead on top of the apparatus.

In 1937 S. E. Forbush[6] and two of the writers[7] found a world-wide influence of a strong magnetic disturbance on the cosmic-ray intensity observed simultaneously in Peru, North America, and Austria; here a decrease of the horizontal force was followed by a decrease of the cosmic-ray intensity.

We concluded that the so-called magnetic effect (ME) on the cosmic-ray intensity is a rather complicated phenomenon and it seemed therefore very interesting to investigate the magnetic effect more closely, using the observations on the Hafelekar for one whole year (March 20, 1936, to March 31, 1937). In this period the Steinke standard apparatus (No. 3) was shielded on all sides by iron (7 cm thick) and an additional screen of lead (10 cm thick). The lead screen was on the outside. Thus the influence of the local radioactive radiation was reduced to less than 0.1 per cent of the total cosmic-ray ionization. In addition the ionization-vessel of the Steinke apparatus was surrounded by a cylinder of zinc separated by five cm from the former and radon-free air was continually forced through this interspace to avoid possible disturbances from the natural radon-content of the air in the room of the Observatory[8].

A second Steinke apparatus (No. 8), shielded by 10-cm lead screens on all sides was in operation at Innsbruck, on the roof of the main building of the University (600 meters above sea-level) for several months. This station was about four miles from the station on the Hafelekar.

Our plan was to investigate the magnetic effect on cosmic rays by different methods, first by comparing the daily mean values, then by analysis of the diurnal period, and lastly by the analysis of the annual period. All observations of the cosmic-ray ionization were of course reduced to normal barometric pressure. The diurnal and annual curves were also reduced to the same outside temperature using the method of multiple correlation. This reduction, however, does not alter the curves appreciably.

Results

(I) *The magnetic effect on the daily mean values*—Figure 1 shows the variation of the daily mean values of the cosmic-ray ionization from March 24 to May 1, 1936, at our two stations. The curves from these stations illustrate beautifully the "variations of the second kind" and prove that these variations indicated simultaneously by two apparatus at two stations, 2300 and 600 meters above sea-level, are real. The third

[5] V. F. Hess and W. Illing, Nature, **135**, 97-98 (1935).
[6] S. E. Forbush, Phys. Rev., **51**, 1108-1109 (1937).
[7] V. F. Hess and A. Demmelmair, Nature, **140**, 316-317 (1937).
[8] For further details see A. Demmelmair, Wien, SitzBer. Ak. Wiss., IIa, **146** (1937).

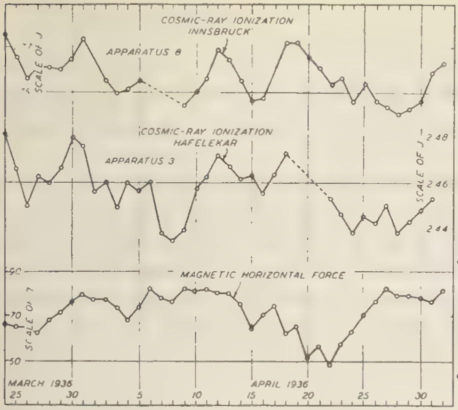


FIG. 1

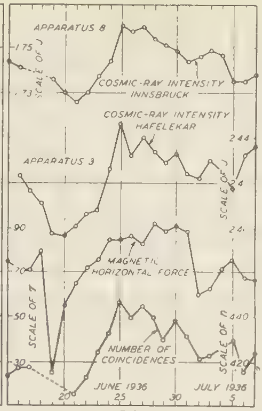


FIG. 2

curve (variation of the Earth's magnetic horizontal force H) is, on the whole, rather similar to the ionization-curves, but not in all its parts.

In Figure 2 the variations as observed with the two Steinke apparatus Nos. 3 and 8 on the Hafelekar and at Innsbruck in June 1936, are shown, together with the variations of the number of coincidences (n) registered by a Geiger-Mueller triple coincidence-counter arrangement (all three tubes vertically above one another, with their axes in the meridian plane). Here once more the *positive* correlation between the horizontal magnetic intensity H and the cosmic-ray ionization as well as the number of coincidences is rather striking. Another illustration of this fact is given in Figure 3, showing the daily means of J and H from October 31 to December 6, 1936.

If we examine these diagrams very closely we cannot overlook the fact that during certain periods the magnetic effect is negative (decrease of J accompanied by increase of H and *vice versa*). In Figure 4 this is shown more clearly, although here, as in all other diagrams, the general tendency of the J- and H-curves is rather in favor of a positive correlation.

We are led to the conclusion that there is a superposition of two

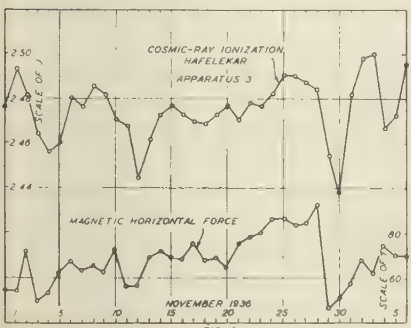


FIG. 3

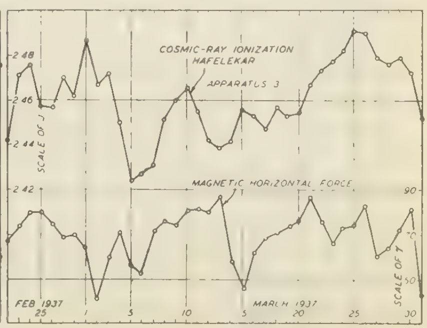


FIG. 4

opposite magnetic effects, the prevalence of one or the other being more or less apparent according to unknown causes.

Statistical analysis supports this point of view. We calculated the correlation and regression-coefficients using Charlier's method of simple correlation between the daily mean values of J and H for three separate series of observations as follows: (1) Observations on the Hafelekar, March to December 1936, and (2) from January to the end of March 1937; (3) observations in Innsbruck from November 1935 to June 1936. Then a separate correlation-table was calculated for the complete one-year series, March 1936 to March 1937 (Hafelekar).

The results are given in Table 1. Here r denotes the correlation-coefficient between ionization (J) and horizontal force (H), ME the magnetic effects (coefficients of regression) in mJ per γ, or in per mille per γ, with their mean errors.

Table 1

Period and station	r	ME	
		mJ per γ	0/00 per γ
March to December 1936, Hafelekar......	-0.337 ± 0.057	-0.667	-0.27 ± 0.04
January to March 1937, Hafelekar.......	$+0.139 \pm 0.104$	$+0.197$	$+0.08 \pm 0.06$
March 1936 to March 1937, Hafelekar....	-0.268 ± 0.051	-0.494	-0.20 ± 0.04
November 1935 to June 1936, Innsbruck..	$+0.132 \pm 0.079$	$+0.234$	$+0.13 \pm 0.08$

From Table 1 it appears obvious that the correlation between the daily means of cosmic-ray ionization (J) and the horizontal force (H) is sometimes positive, sometimes negative. A long series, like that from March 1936 to March 1937, gives a negative correlation, as Hess and Illing had found in 1933. But the magnitude of the correlation-coefficient is again rather small. Nevertheless it can be said that for observations on the Hafelekar the existence of a negative correlation has been proved at least formally. The mean error of r is only one-fifth of the value of r for the one-year series. The observations in Innsbruck (seven months) give a very small positive correlation, its mean error being of the same magnitude as the coefficient r itself.

The magnetic effect (ME) found on the Hafelekar is about three times smaller than the one given by Barnothy and Forró[3]. This is not surprising since they used a "vertical-coincidence" arrangement which is acted upon by a much narrower beam of rays than the ionization-chamber arrangements.

(II) *The diurnal period*—Figure 5 shows the average diurnal variation of the cosmic-ray ionization, as derived from the observations on the Hafelekar during one year (1936-37) together with the diurnal variation of the magnetic horizontal intensity, according to local time (middle European time). The cosmic-ray ionization-observations are reduced to the normal pressure, 580 mm on the Hafelekar, and to the average outdoor temperature of $-1°$ C by the method of multiple correlation.

The anti-parallelism of the two curves is very striking and seems to support the hypothesis of Ross Gunn, mentioned in the introduction of this paper. Nevertheless it must not be overlooked that the maximum of the cosmic-ray ionization occurs two hours later than the maximum

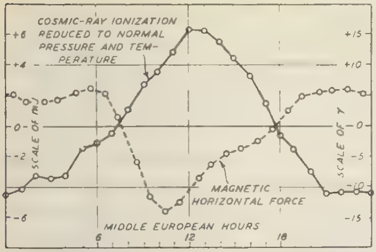


FIG. 5—DIURNAL VARIATION ON LOCAL TIME

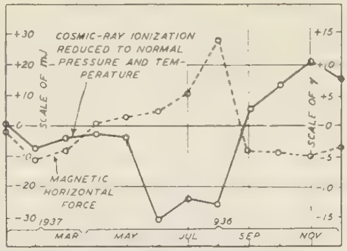


FIG. 6—SEASONAL VARIATION

of the horizontal force H. The difference between maximum and minimum amounts to $0.010J = 10mJ$ for the ionization (about 0.4 per cent of the total ionization) and to about 0.00020 gauss ($=20\gamma$) for the horizontal force (0.01 per cent of the total horizontal magnetic intensity). From these data we can estimate a magnetic effect of $-0.5mJ$ per γ. The statistical analysis by Charlier's method gives, in excellent agreement with this, a ME of (-0.505 ± 0.022) mJ per γ or -0.206 per mille per γ. This effect is of the same magnitude as the one calculated from the daily mean values of Section I. The correlation-coefficient between J and H from the diurnal curves in Figure 5 is as high as $r = -0.901 \pm 0.039$.

III. *The seasonal period*—If we plot the monthly means of cosmic-ray intensity (reduced to 580-mm barometric pressure and to $-1°$ C) and of the horizontal force H (Fig. 6) during one year, we see that the seasonal variation of J and H are anti-parallel. The monthly mean values of the cosmic-ray ionization during the summer are decidedly lower than in winter. This has been found also in former years on the Hafelekar[9] and at other stations[10]. On the Hafelekar the maximum difference between the winter and summer mean values amounts to $50mJ$ (about two per cent of the total cosmic-ray ionization) while the magnetic force (monthly means) during the year 1936-37 varied only about 20γ, that is, not more than in the average during the day. The correlation from the seasonal variation (Fig. 6) is $r = -0.752 \pm 0.126$ which is almost as high as in the case of the diurnal variation. The ME calculated therefrom $-2.37mJ$ per γ (about one per mille per γ) is five times as large as in the case of the diurnal variation.

(IV) *General discussion* We are confronted now with a very puzzling situation.

(1) The inspection of the diurnal and annual curves of J and H would lead to the conclusion that there is decidedly a negative correlation increase of J caused by a decrease of H and *vice versa*. In general, this is also supported by the statistical analysis of the non-periodical variations of the daily mean values in a series of observations for one year (1936-37 and 1933), giving a negative correlation-coefficient -0.268 and a ME of -0.20 per mille per γ, while from the diurnal variation an effect of the same magnitude (-0.2 per mille per γ) was derived. The curve of the seasonal variation, however, yields a much greater magnetic effect (as high as -1 per mille per γ) with the maximum of ionization in winter,

[9] R. Steinmaurer, Beitr. Geophysik, **45**, 148-183 (1935).

[10] B. F. J. Schonland, B. Delatizky, and J. Gaskell, Terr. Mag., **42**, 137-152 (1937); A. Corlin, Ann. Obs., Lund. No. 4, *A*71-*A*73 (1934).

when the Sun is in the lowest position above the horizon whereas the diurnal curve shows the maximum of ionization at noon, when the Sun is nearest to the zenith.

An explanation of the daily period of the cosmic radiation (with the maximum at noon) has been given tentatively by Ross Gunn (as already mentioned above[1]) who says: ". . . diamagnetism in the ionosphere distorts the Earth's magnetic field in much the same way as the solar magnetic field is distorted, except the distortion is much less and is confined pretty much to the sunlit side of the Earth. This diurnal distortion decreases the magnetic field above 200 km by 0.1 per cent or more in noon-day regions so that the cosmic rays (or their secondaries) are less deflected and produce locally more intense ionization at low levels."

This explanation has been criticized by Julian L. Thompson[11] who calculated from the theory of Lemaître and Vallarta that the diurnal variation of the cosmic radiation caused by the diurnal change of the horizontal magnetic force would amount to only ± 0.0068 per cent (at latitude 45°) while the observed amplitude of the diurnal variation is about ± 0.2 per cent of the total cosmic-ray ionization.

L. Janossy[12] tried to explain the diurnal period of the cosmic-ray ionization by the effect of the magnetic dipole moment of the Sun. Certain difficulties were encountered and it is quite uncertain as yet whether a quantitative explanation is possible on the basis of a solar magnetic influence.

Therefore it will be best to discuss our experimental results first without accepting definitely any of the theoretical explanations thus far offered.

(2) From the curves giving the variations of J and H from day to day, it seems evident that very often the variations of J and H are parallel, that is, *a positive correlation between cosmic-ray intensity and the Earth's magnetic horizontal force does very often exist.*

This conclusion is corroborated by the recent observations of Forbush already mentioned, as well as by those of the writers[6, 7] who found that during a severe magnetic storm in April 1937, a total decrease of the magnetic horizontal force of about 100γ in four days was accompanied by a decrease of the cosmic-ray intensity of nearly five per cent at three widely separated stations (Cheltenham, U.S.A.; Huancayo, Peru; and Hafelekar, Austria). Afterwards a similar increase of J and H was observed. The positive ME calculated by us for these observations amounts to $+1.4$ mJ per γ corresponding to $+0.57$ per mille of the cosmic-ray total intensity per γ. This positive ME is three times as great as the "normal" negative ME deduced from the daily means of the year 1936-37.

S. Chapman [13] has recently offered a very plausible explanation for this positive magnetic effect on cosmic rays during magnetic disturbances. He and Ferraro assume—in a modification of an idea of C. Störmer—that the Earth is encircled by electronic ring-currents (positive and negative charges moving in orbits in opposite directions) at a radial distance of a few earth-radii.

[11] J. L. Thompson, Phys. Rev., **50**, 869 (1936.)

[12] L. Janossy, Zs. Physik, **104**, 430-433 (1937).

[13] S. Chapman, Nature, **140**, 423-424 (1937).

If during a solar outburst these electronic ring-currents are increased the magnetic dipole moment of the Earth is strengthened for regions outside of these rings or shells, while inside, near the surface of the Earth, the magnetic field of the Earth is reduced. The increase of the Earth's magnetic field in the outer space produces a considerable deflection of the normal paths of the cosmic-ray particles, thus reducing the observed cosmic-ray intensity on the Earth.

The positive *ME* observed by Forbush and the writers seems to make it possible to estimate the radial distance of these electronic ring-currents from the center of the Earth, according to Chapman.

Chapman's theory seems to offer not only an explanation of the positive *ME* during magnetic storms but also of the "normal" negative effect, if we assume that these ring-currents are always present; in normal times a steady state is reached, when as many positive and negative elementary charges are disappearing by recombination per unit-time as are supplied by the Sun. On the day-side of the Earth, electrons would continually enter the ring-zones. Here the density of the currents would be somewhat higher than on the other side; thus on the day-side, the magnetic field inside these ring-zones would be weakened. If we further assume that the corresponding increase of the outer field is not strong enough to influence the normal paths of the more penetrating primary particles of the cosmic radiation, as opposed to the case during severe magnetic storms, the "normal" negative *ME* could be explained. The inside decrease of the magnetic field would influence the paths of the softer secondaries created within the atmosphere; these would be less deflected and thus a noon-maximum of ionization could be expected.

Naturally this explanation will have to be analyzed quantitatively before it is accepted.* It would be very satisfactory to derive an explanation of the positive and the negative magnetic effect on cosmic rays from one theory.

The negative magnetic effect as derived from the seasonal variation of the cosmic-ray ionization cannot, however, be explained without resorting to other hypotheses. We have found that in summer, when the horizontal force is at its maximum, the cosmic-ray intensity is considerably lower. The correlation is rather strong ($r = -0.75 \pm 0.13$) and from this seasonal variation a *ME* of $-2.4mJ$ per γ or -1 per mille of the cosmic-ray intensity per γ was derived formally (see Section II).

This effect is at least five times as great as the normal negative *ME* derived from the diurnal variation and—as already pointed out at the beginning of our discussion—is in the sense opposite to that which would be expected from the relative positions of the Sun to the Earth.

The seasonal variation of the cosmic-ray ionization has also been observed in the Southern Hemisphere by Schonland and his collaborators[10] under similar experimental conditions. The amplitude of the seasonal variation at Capetown (latitude 34° south) is however less than one-half of that on the Hafelekar. This would indicate that the

*There are two weighty objections, as Prof. Chapman kindly pointed out in a letter to one of us: First the daily variation of H is in lower latitudes (to about 30° north or south) opposite to that given in Figure 5. Then, in adapting Chapman's suggestion of the outer ring-currents for the explanation of the daily variation of J, it must not be overlooked that if the ring-particles have velocities of 10^7 cm/sec or more they would circulate around the ring in less than one hour, and this would smooth out any daily influence of the Sun on the ring. C. Störmer in a letter to one of us writes that he thinks that the magnetic effect in the diurnal curves is due to currents in the outer atmosphere. These will be of a different shape and origin from those in the outer equatorial ring. Therefore the existence of two opposite effects (as termed ME_1 and ME_3 in the abstract of this paper) would not at all be surprising.

harder component of the cosmic radiation shows less seasonal change. Moreover in Capetown the seasonal variation is smoothed out by correction for temperature. This is not the case with the observations on the Hafelekar.

Schonland concluded from his observations that for the seasonal variation of the cosmic-ray intensity, the change of the stratification of the atmosphere is solely responsible.

Our observations in the Northern Hemisphere do not support this point of view. Nevertheless it is well to keep in mind that the correlation between magnetic horizontal force and cosmic-ray intensity in our seasonal curve could also be accidental. In fact the maximum of H in Figure 6 is in August while the minimum of J occurs one or two months earlier and the annual variation of H, as found in the average of other stations shows minima near each equinox.

Therefore it cannot be said at present whether the negative ME derived from the seasonal curves of J and H on the Hafelekar is a real magnetic effect. If it is, its magnitude and sign as well as the opposite behavior to the ME from the diurnal curve with respect to the relative position of the Sun indicate that they are entirely different. Further observations will be necessary at other stations before it will be possible to draw well-founded conclusions as to the true nature of the seasonal variation of the cosmic radiation.

Summary

Our observations indicate the existence of several effects of the Earth's magnetism on the observed cosmic-ray intensity. From the non-periodic fluctuations from day to day one can see that the variations of J and H are sometimes parallel, sometimes anti-parallel. In the average for one year the latter effect prevails. The diurnal curves of J and H according to local time also yield a negative correlation between J and H, while during magnetic disturbances a positive correlation was observed over the whole Earth. Both effects can be explained tentatively on the basis of Chapman's hypothesis although this explanation is open to serious objections.

Another negative effect can be derived from the seasonal change of J and H. It is doubtful as yet whether this effect is a true magnetic effect. An explanation cannot be given at present on account of the paucity of experimental data.

We wish to thank Hofrat Dr. M. Kofler and the Meteorologische Zentralanstalt in Vienna for kindly placing the magnetic data of the Magnetic Observatory from Wien-Auhof at our disposal.

Physikalisches Institut,
Universität Graz,
Graz, January 22, 1938

NON-SEASONAL CHANGE OF F_2-REGION ION-DENSITY

L. V. Berkner and H. W. Wells

Abstract—Observation of noon F_2-region ion-density at stations in both the Northern and Southern hemispheres shows that variations in one are not predicted at the other with the hypotheses which have been advanced to explain them. Observations made at Washington by the National Bureau of Standards, and at Watheroo by the Department of Terrestrial Magnetism, Carnegie Institution of Washington, are analyzed. It is found that a variation-component exists in the data from 1935-37 which is in the same phase at both stations. This term has a principal period which, over the period studied, is indistinguishable from one year. Its amplitude is about equal to that of the seasonal variation, maintaining a nearly constant ratio to the changing background ion-density. This non-seasonal variation is, therefore, of sufficient amplitude, if neglected, to vitiate quantitative calculations of seasonal effects based upon the observations from one hemisphere alone. While the average magnitude of the background ion-density is closely related to annual averages of solar activity, departures of the non-seasonal component from the mean show no sensible correlation with monthly sunspot-averages. The data and methods are examined to determine whether inhomogeneity of data, or methods of analysis, could induce the effect artificially. It is concluded that the amplitude of such induced errors must be small compared to the amplitude of the non-seasonal effect. Application of the heating hypothesis in its present form leads to a heating ratio more than 100 times as great at Washington as at Watheroo, which does not seem probable. Correction of the data for the non-seasonal effect leads to a heating ratio for summer to winter of about 10 to 1 for both stations. Possible causes of the non-seasonal term are considered. The paucity of data from widely separated locations through the 24 hours limits speculation. In reviewing the implications of the data, the writers are inclined to the view that the cause is associated with the Earth or its motion, though the arguments presented on the basis of existing data are not sufficient to establish this view unequivocally.

Observation of F_2-region ion-density in Northern and Southern hemispheres indicates that variations of maximum ion-density seem quite inconsistent with the hypotheses which have been advanced to explain them. By use of such hypotheses, it is not possible to predict variations at a station in one hemisphere from changes which occur at a station in the other. In a paper in this Journal in June 1936 [see 1 under "References" at end of paper], it was shown that observed variations at Watheroo and Washington, in opposite hemispheres, were not simply reversed in phase as expected from a calculation of supposed seasonal effects. On the contrary it appeared that a variation-component of large amplitude and of period approximately one year occurred in the same phase at both stations, and that this effect masked the true seasonal variation. This was designated as an "annual" variation in contradistinction to variation-components of period one year but opposite phase in the two hemispheres which is the principal seasonal variation. It would have been better, perhaps, to have used the term "non-seasonal" to distinguish from seasonal effects, though present data indicate no distinguishable difference from a period of one year for the principal non-seasonal variation.

Data which have accumulated since that paper permit a more thorough consideration of these seeming discrepancies between variations of F_2-region ion-densities measured at noon at Washington and Watheroo. A simple method is used to separate the variations having opposing phase in the two hemispheres from the background appearing at both stations. Over the three-year interval from 1935 to 1937, a large variation-component exists which is in the same phase at both stations. This has a principal period of about one year, and an amplitude approximately equal to the amplitude of the component of variation which is in the opposite phase at the two stations. It is not a seasonal variation

in the sense that such a seasonal variation must be as the same function of the local zenith-angle in both hemispheres. This variation is therefore of sufficient amplitude, if neglected, to vitiate quantitative calculations of seasonal effects based upon one hemisphere alone. It is found further that the rise in annual averages of ion-density shows an almost perfect correlation to annual average sunspot-numbers over the three-year period. At the same time, perhaps surprisingly, there is no correlation between deviations of in-phase fluctuation of ion-density from the curve through annual means and of similar deviations of sunspot-numbers. Therefore the in-phase variation cannot be readily explained by resort to sunspot-changes, nor is it permissible to correct monthly means of F_2-region ion-density in accordance with monthly sunspot-numbers.

Data from Washington and from Watheroo have been used because of their continuity. The data from Watheroo are obtained from observations at the Watheroo Magnetic Observatory of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, in Western Australia (30° south, 116° east). At Washington (39° north, 75° west) observations of the National Bureau of Standards published by Kirby, Gilliland, Smith, and Reymer [2, 3] form the longest continuous series of observations available from the Northern Hemisphere. Data from other stations, principally the Huancayo Magnetic Observatory in the Southern Hemisphere, and from a number of localities in Europe and Asia have also been examined. The July dip in maximum ion-density seems typical in the data of all stations studied, strengthening somewhat the generality of conclusions drawn from analysis of the data for Washington and Watheroo. Nevertheless one may expect that as these variations are revealed in better detail, it will be possible to learn more of the effect here discussed from their similarities or differences. Especially important is the need of more complete and homogeneous data from all stations through the 24 hours.

In Figure 1 is plotted monthly averages of F_2-region critical frequency ($f_{F2}{}^0$) measured at noon at Washington and at Watheroo over the

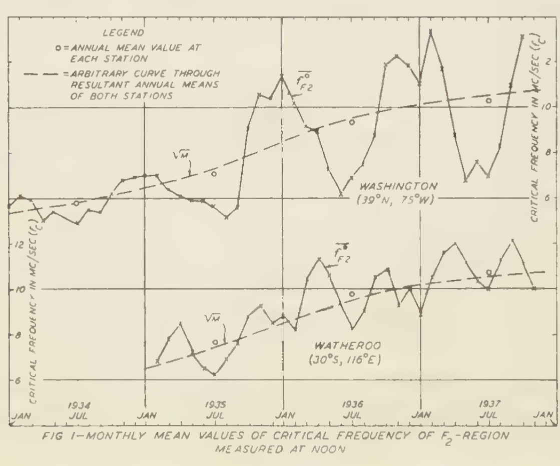


FIG 1—MONTHLY MEAN VALUES OF CRITICAL FREQUENCY OF F_2-REGION MEASURED AT NOON

TABLE 1—*Monthly average values of F_2 critical frequency at noon for "o" wave-component*

Month	Washington				Watheroo		
	1934	1935	1936	1937	1935	1936	1937
January	5.7	7.0	11.4	11.1		8.8	8.9
February	6.1	7.0	10.2	13.4	6.8	8.2	10.5
March	5.9	6.4	9.2	11.7	7.9	10.4	11.6
April	5.0	6.1	9.0	8.8	8.5	11.3	12.0
May	5.4	5.9	7.3	6.8	7.2	10.6	11.2
June	...	5.9	6.2	7.6	6.5	9.4	10.3
July	4.9	5.7	6.9	7.0	6.2	8.2	10.0
August	5.5	5.2	7.5	8.3	6.9	9.0	11.3
September	5.4	5.6	8.8	11.0	7.6	10.5	12.1
October	6.2	9.1	11.9	13.1	8.8	10.9	11.1
November	6.8	10.6	12.3	13.4	9.2	9.3	10.0
December	6.9	10.4	11.9	11.7	8.5	10.0	9.5

three-year interval from 1935-37. These values are tabulated in Table 1.

In this paper we shall be interested primarily in variation of maximum ion-density. This is expressed by

$$N=k(f_c^0)^2 \qquad (1)$$

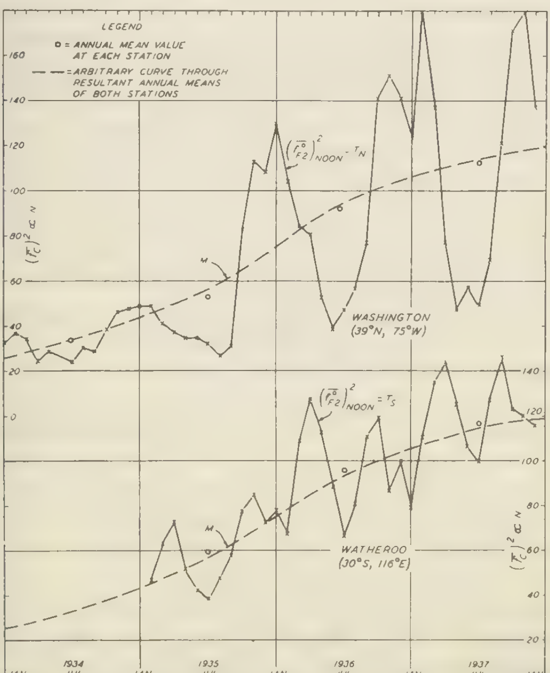


FIG. 2—MONTHLY MEAN VALUES OF F_2 CRITICAL FREQUENCY SQUARED AS MEASURED AT NOON

where f_c^0 is critical frequency for *o* wave-component in mc/sec, and $k=1.24\times10^4$ using Lorentz correction $a=0$, and $k=1.86\times10^4$ using $a=1/3$. In succeeding figures involving ion-density, ordinates are plotted in f_c^2, being proportional to N. Variation in square of monthly mean critical frequency at the two stations is illustrated in Figure 2. The square of the mean is not the mean of the squares, so that strictly speaking this is not mean of ion-density. This should be obtained from the relation*

$$\overline{N}\propto(\overline{f_c^2}) \qquad (2)$$

Because of inhomogeneity of data which is obtained at each station for only part of the days each month, this refinement does not seem justified. Consequently the approximate expression

$$\overline{N}\propto(\overline{f_c})^2 \qquad (3)$$

is used, where $\overline{f_c}$ is taken from available observations over an interval of one month. In comparing a number of sample values of $\overline{N}$ obtained by methods (2) and (3) the result obtained by the first never exceeded that by the second by more than one or two per cent. With this restriction the ordinates of Figure 2, and succeeding figures of ion-density, can be considered proportional to average ion-density measured over the month at noon.

The nature of the discrepancy between the two stations can be seen from Figures 1 and 2. The variation of F_2-region maximum ion-density at Washington has a single important maximum in northern winter and a single important minimum in northern summer. On the other hand the variation at Watheroo has two maxima of comparable importance at the equinoxes, and two minima of comparable importance, one in winter and the other in summer [4]. It would be manifestly untrue to say that the variation at Watheroo referred to southern mid-winter as origin of time is even approximately the same as that at Washington referred to the northern midwinter as the origin of time, and this destroys the basis for assuming that the variation of either station represents what is customarily regarded as a seasonal effect.

Before proceeding further with an examination of this difficulty, let us examine the annual mean of ion-density at the two stations. These with the resultant annual mean for both are given in Table 2.

TABLE 2—*Annual means of noon-values of F_2-region ion-density*

Year	Washington	Watheroo	Both	Ratio (Wo/Wn)
1934	4.21×10^5	....	....	....
1935	6.61×10^5	7.38×10^5	6.98×10^5	1.11
1936	11.45×10^5	11.85×10^5	11.64×10^5	1.03
1937	14.05×10^5	14.30×10^5	14.15×10^5	1.03
Means	10.66×10^5	11.12×10^5	10.93×10^5	1.05

*It comes to one's attention forcibly here that only arithmetic means of critical frequency have been published by all investigators. What is really wanted is not the arithmetic mean, but the *root mean square* value of critical frequency for the month. It seems to us that this value will be more valuable to both the physicist and the engineer. While the difference will be ordinarily small, it is enormously significant n the mean where decision as to the ionizing source or process may rest upon it.

Corresponding values of annual mean are plotted in Figure 2, and the resultant annual means of both stations are connected by a dashed line which is common in both graphs. An arbitrary smooth curve has been selected to connect them rather than straight lines, though there is little choice between straight lines and the smoothed curve shown. Hereafter this smoothed curve will be referred to as M. While these means fall remarkably close together, the mean at Watheroo is always a little higher than that at Washington. This is as expected when it is remembered that Watheroo is the nearer to the equator. If the mean maximum ion-density of the region is assumed proportional to the mean square root of cosine of the Sun's zenith-angle

$$\overline{N} \sim \overline{\sqrt{\cos z}} \tag{4}$$

then the computed ratio of ion-density at Watheroo to that at Washington is about 1.07. This is not greatly different from the average observed ratio over the three-year period. We see then that any seasonal or non-seasonal variations must be reasonably consistent at the two stations, for it seems improbable that the annual means are so well related by chance.

To better analyze these effects we divide the variation at the two stations into two components. One component is in the same phase at both stations (the in-phase component). This component is in reality the monthly average of both. The other component is in the opposite phase at both stations (the out-of-phase component). It is first assumed that the effect of difference of latitude from the equator will be negligible (30° compared with 39°) with respect to the principal variations. We will then examine this treatment to infer its interpretation and to de-

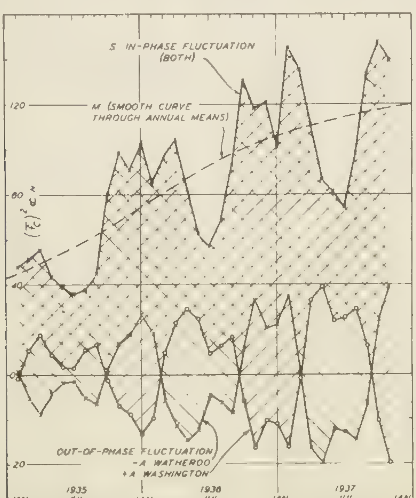


FIG. 3—ION-DENSITY PLOTTED WITH RESPECT TO OUT-OF-PHASE FLUCTUATION ±A

termine the extent to which neglect of difference in latitude will affect the result. It will be shown that the effect due to difference of latitude of the two stations is partly counterbalanced by ellipticity of the Earth's orbit and that the relative latitudes of the two stations is almost ideal for this study.

Let the variation of monthly mean ion-density measured at Washington be designated by T_N, and at Watheroo by T_S. Then if we subtract the two functions, only out-of-phase variations remain, while the background common to both stations disappears. If they are added, the out-of-phase variations drop out, while only the in-phase background simultaneously common to both stations remains. This is the monthly average of both stations. Performing this operation

$$(T_N - T_S)/2 = A \qquad (T_N + T_S)/2 = S \tag{5}$$

where A is the out-of-phase and S the in-phase variation in the two hemispheres.

The application of this procedure is shown in Figure 3 where functions $+A$, $-A$, and S are plotted using the same ordinates as in Figure 2. The ordinate-differences $(S+A)$ and $(S-A)$, respectively, are exactly the variation curves T_N and T_S which were plotted in Figure 2. In essence, Figure 3 shows the common background ion-density, S, as a non-linear base-line against which the variation-curves $+A$ at Washington and $-A$ at Watheroo are plotted downward as ordinates. This, perhaps, can be seen more clearly in Figure 4 where S is plotted with respect to $+A$ only. In Figure 4, two curves for S appear, the upper, to which is referred the ion-density at Washington, and the lower which is inverted, and to which is referred the ion-density at Watheroo. The positive direction is always measured from S to A; thus the shaded regions above A and below A give the variation of ion-density at Washington and at Watheroo, respectively. As in Figure 3, the out-of-phase variation can be regarded as the ion-density at Washington, or at Watheroo, respectively, referred to the appropriate variable base-line S. Plotted in this way, S is the component of variation common to both stations at the same time.

There are several important points which are now evident. (1) The background ion-density given by curve M shows a steady increase on an average during the interval studied. (This is a necessary consequence after the increase in annual means shown in Table 2, because over the period of a year effect of seasonal terms is zero.) (2) There remains a fluctuation in the background ion-density which is present simultaneously at both stations. This fluctuation is given by curve S. The principal part of this fluctuation has a period of about one year with a minimum in July and a maximum in the months about January. (3) The out-of-phase variations (which are primarily seasonal ones) are shown by curve A. These have a principal period of one year with a minimum near midsummer and a maximum near midwinter. (4) Over the interval, the amplitude of both variations (A and S) has increased about in proportion to the increase in annual means. Table 3 better illustrates this last point, where ratios of the annual means and of departures from the means are shown for 1935 and 1937 with respect to 1936 as reference-year.

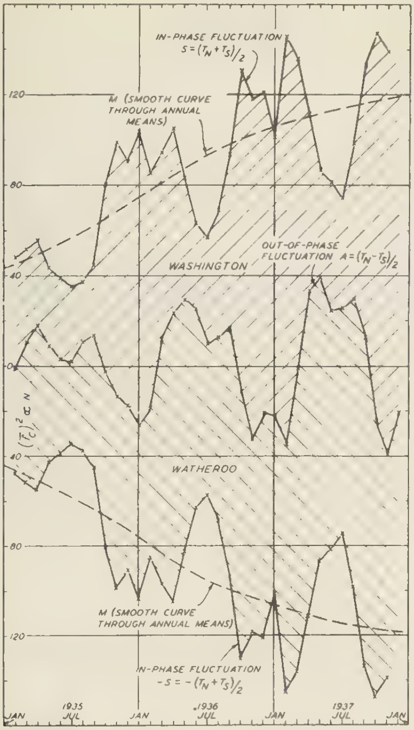


FIG. 4—ION-DENSITY PLOTTED WITH RESPECT TO OUT-OF-PHASE FLUCTUATION +A (ORDINATE DIFFERENCES YIELD CURVES OF FIGURE 2)

TABLE 3—*Ratios of annual means and departures from means referred to 1936*

Year	1935	1936	1937
Ratio of annual means	0.60	1.00	1.22
Ratio of departures from mean in A	0.47	1.00	1.29
Ratio of departures from mean in S	0.74	1.00	1.09

In order to see the nature of these variations in better detail, they are reduced to the reference-epoch, July 1936, in the manner suggested by Table 3. This reduction is shown in Figure 5 where ordinates are changed in proportion to M'/M, where M' is the annual mean for 1936, and M is the smooth curve through the annual means. As anticipated from Table 3 variations are thus reduced to nearly constant amplitude over the interval.

Table 3 and Figure 5 just given show that the in-phase and out-of-phase terms are a fairly constant percentage of the background

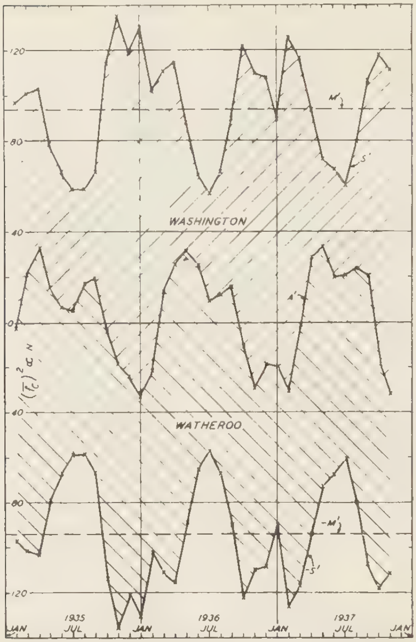


FIG. 5—GRAPH OF FIGURE 4 REDUCED TO STANDARD EPOCH, JULY 1936, ACCORDING TO A'=A(M'/M), AND S'=S(M'/M), WHERE M'=ANNUAL MEAN FOR 1936

on-density over the interval. The in-phase variation, which is given in Figure 4 by curves S, can be expressed by

$$S=M(1+B)$$

where M is given by the curve of smooth annual means, and B is another variable given by curves S' of Figure 5. It is apparent that to a first approximation the B-variation repeats itself both in phase and amplitude over the three years under consideration. This means that B is to a first approximation a periodic function of period one year over the interval. This appears to be no accident. That variation-term B is not correlated with sunspot-fluctuation will be shown later. If data over a number of years establish this variation of B more rigorously than is possible with the present information, it is implied that this variation arises from causes associated with the Earth or its motion.

In the ensuing discussion, we examine the nature of seasonal effects so that the significance of the methods just applied may be understood. We will regard a seasonal effect as one which is the same function of local zenith-angle in the two hemispheres at equal and opposite latitudes. This definition ignores such effects. due to local conditions, as the relative distribution of masses of land and water at the surface, or circulation of the Earth's outer atmosphere under the influence of the Earth's

magnetic field, which might produce conditions which were unique at a particular station. With the method used, it is clear that effects which occur at one station, and which do not occur at the other, will appear in the analysis with half of the effect in the in-phase and half of the effect in the out-of-phase terms. We will, however, proceed with the definition of seasonal effect based upon the local zenith-angle alone, to determine the nature of the remaining change which is non-seasonal under this definition. We will then examine the available data to determine whether the non-seasonal changes so derived could be due to unique effects occurring at one station alone, or whether the variation is in fact non-seasonal.

We must now examine this treatment more thoroughly to infer its interpretation. The general variation of maximum ion-density can be represented by a Fourier series in two variables, namely, the latitude λ and the time t.

$$T = M + \sum_{m=1}^{m=\infty} \sum_{n=1}^{n=\infty} [a_{mn} \sin m\lambda \sin nt + b_{mn} \sin m\lambda \cos nt + c_{mn} \cos m\lambda \sin nt + d_{mn} \cos m\lambda \cos nt] \tag{6}$$

Putting the latitude of a station as λ_0, the following notation can be made

$$\left.\begin{aligned} \alpha_n &= \sum a_{mn} \sin m\lambda_0 \\ \beta_n &= \sum b_{mn} \sin m\lambda_0 \\ \gamma_n &= \sum c_{mn} \cos m\lambda_0 \\ \delta_n &= \sum d_{mn} \cos m\lambda_0 \end{aligned}\right\} \tag{7}$$

Assume the latitudes of Watheroo and Washington to be equal but of opposite sign. Using the appropriate sign for the latitude in (7), variations at Washington and Watheroo, respectively, become

$$\left.\begin{aligned} T_N &= M + \sum_{n=1}^{n=\infty} [(\alpha_n + \gamma_n) \sin nt + (\beta_n + \delta_n) \cos nt] \\ T_S &= M + \sum_{n=1}^{n=\infty} [(-\alpha_n + \gamma_n) \sin nt + (-\beta_n + \delta_n) \cos nt] \end{aligned}\right\} \tag{8}$$

and

$$\left.\begin{aligned} (T_N + T_S)/2 &= M + \sum_{n=1}^{n=\infty} (\gamma_n \sin nt + \delta_n \cos nt) = M + \sum_{n=1}^{n=\infty} S_n \cos (nt + \epsilon_n) \\ (T_N - T_S)/2 &= \sum_{n=1}^{n=\infty} (\alpha_n \sin nt + \beta_n \cos nt) = \sum_{n=1}^{n=\infty} A_n \cos (nt + \psi_n) \end{aligned}\right\} \tag{9}$$

We have regarded a seasonal effect as one which is the same function of local zenith-angle in the two hemispheres in equal and opposite latitudes. We define, then, a seasonal component as a term of the above series whose phase differs by six months in the two hemispheres. Then in the above expressions, the even harmonics in S, $[S_{2n}\cos(2nt+\epsilon_{2n})]$, and the odd harmonics in A, $\{A_{2n-1}\cos[(2n-1)t+\psi_{2n-1}]\}$, are all seasonal terms, while the remaining terms are not seasonal terms. Thus the seasonal variation is given by

$$V=A_1\cos(t+\psi_1)+S_2\cos(2t+\epsilon_2)+A_3\cos(3t+\psi_3)+S_4\cos(4t+\epsilon_4)\\ \ldots\ldots+A_{2n-1}\cos[(2n-1)t+\psi_{2n-1}]+S_{2n}\cos(2nt+\epsilon_{2n}) \qquad (10)$$

and the non-seasonal variation by

$$W=S_1\cos(t+\epsilon_1)+A_2\cos(2t+\psi_2)+S_3\cos(3t+\epsilon_3)+A_4\cos(4t+\psi_4)\\ \ldots\ldots+S_{2n-1}\cos[(2n-1)t+\epsilon_{2n-1}]+A_{2n}\cos(2nt+\psi_{2n}) \qquad (11)$$

In the observed data even harmonic terms of the sum, $S=[(T_N+T_S)/2]$, are seasonal terms, while odd harmonics are not seasonal. Likewise in the difference, $A=[(T_N-T_S)/2]$, odd harmonics are seasonal terms and even harmonics are not seasonal. Because only even harmonic terms of S occur in V, and of A in W, certain generalizations can be made concerning the data of Figure 5. Odd and even harmonics of curve S' can be separated by the following operation.

$$\left.\begin{aligned}(T'_N+T'_S)_\epsilon/2-(T'_N+T'_S)_{\epsilon\pi}/2&=2M'+2S'_{odd}\\(T'_N+T'_S)_\epsilon/2+(T'_N+T'_S)_{\epsilon\pi}/2&=2S'_{even}\end{aligned}\right\} \qquad (12)$$

where subscript ϵ refers to a particular ordinate, and subscript $\epsilon\pi$ refers to an ordinate just six months different. All primed components refer to values reduced to fixed epoch July 1936 by factor (M'/M). Odd and even harmonics can be similarly separated in A'.

$$\left.\begin{aligned}(T'_N-T'_S)_\epsilon/2-(T'_N-T'_S)_{\epsilon\pi}/2&=2A'_{odd}\\(T'_N-T'_S)_\epsilon/2+(T'_N-T'_S)_{\epsilon\pi}/2&=2A'_{even}\end{aligned}\right\} \qquad (13)$$

These operations are permissible because ordinates of odd harmonics separated by six months are equal, and opposite in sign, while ordinates of even harmonics separated by six months are equal and of the same sign. The composition of the seasonal changes V' and the non-seasonal changes W' can now be made. These are

$$\left.\begin{aligned}V'_N&=A'_{odd}+S'_{even}\\V'_S&=-A'_{odd}+S'_{even}\\W'_N&=M'+S'_{odd}+A'_{even}\\W'_S&=M'+S'_{odd}-A'_{even}\end{aligned}\right\} \qquad (14)$$

so that from (12) and (13)

$$\left.\begin{aligned}V'_N&=(T'_{N\epsilon}+T'_{S\epsilon\pi})/2\\V'_S&=(T'_{S\epsilon}+T'_{S\epsilon\pi})/2\\W'_N&=(T'_{N\epsilon}-T'_{S\epsilon\pi})/2\\W'_S&=(T'_{S\epsilon}-T'_{N\epsilon\pi})/2\end{aligned}\right\} \qquad (15)$$

Thus from (15) seasonal and non-seasonal changes can be had by direct resort to the data. The method of (14), however, is more desirable for in this way odd and even harmonic components can be obtained separately. This has been done in Figure 6 for each year separately, and the

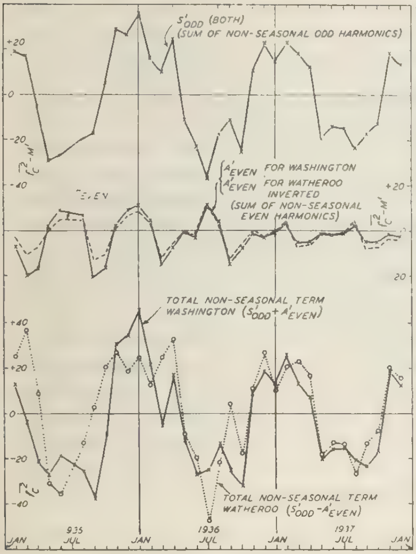


FIG 6A—COMPOSITION OF NON-SEASONAL TERM FROM ODD AND EVEN HARMONICS

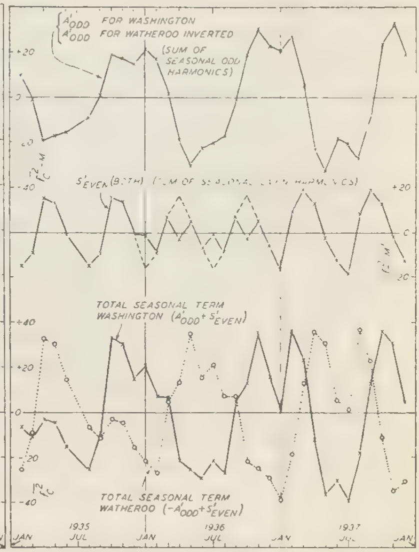


FIG. 6B—COMPOSITION OF SEASONAL TERM FROM ODD AND EVEN HARMONICS

result combined in graphs. The odd harmonics of the non-seasonal change (S'_{odd}) of Figure 6*A* are now seen clearly to form the principal, if not the whole, part of the non-seasonal change. The approximation of the non-seasonal change to a harmonic of period one year which was made earlier is now seen to be very nearly correct. With regard to the even harmonics of non-seasonal change (A'_{even}), they are small and of changing amplitude, suggesting that correction (M'/M) should not have been applied to them. The dashed line (A_{even}) shows that they are small and about constant amplitude when correction ($M'\ M$) is removed. This strongly suggests that curve A_{even} is a correction-curve of amplitude equal to errors from the true mean. Application of corrections from this curve by methods outlined later would greatly smooth curves for S' and A'. It is clear that under any circumstances, either exclusion or inclusion of this small contribution in the non-seasonal term in no way affects the general conclusions.

Components of seasonal change are shown in Figure 6*B*. Here odd-harmonic terms (A'_{odd}) again form the principle variation, and are reversed in phase in the two hemispheres. Even harmonic terms (S'_{even}) are by no means negligible, and appear to be formed mainly of a second harmonic whose maximum positive values occur at the equinoxes. The dashed corrections on this curve show the result of changing two

monthly values in the data by small amounts, a modification which we believe to be justified by indicated corrections to the data described later. The origin of the second harmonic term is not entirely clear. As we show later, an artificial second harmonic of small amplitude is induced by assumption of equal polar distances of the two stations, though this does not seem to be enough to produce the observed effect. If the ion-density were to diminish appreciably between regions F_1 and F_2, when they were widely separated, such a term would arise because of merging of these regions near winter. It might be possible upon further consideration of this point to develop quantitative ideas concerning the ion-density between F_1- and F_2-regions in this way.

One further generalization can be made. The mean amplitude of odd harmonics of non-seasonal change, W, can be obtained from average departures from the mean without regard to sign over one period in S, for over each half-period the even harmonics sum to zero. The mean amplitude of odd harmonics of seasonal change is similarly obtained from curve A. Therefore the ratios of average departures from the mean for successive years, given by Table 3, yield in reality the important ratios of principal non-seasonal and seasonal changes, respectively.

Consider the effect of the assumption that the stations have the same polar distance. Actually Watheroo is the nearer to the equator by 9°. There are three immediate factors which must be considered concerning this assumption to determine whether the non-seasonal effect could have been artificially induced by this assumption in treatment of the data:

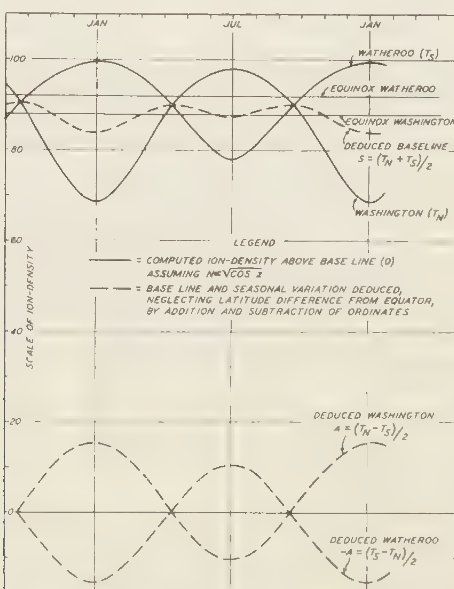


FIG 7—EFFECT OF DIFFERENCE IN POLAR DISTANCE OF WASHINGTON AND WATHEROO

(1) Difference in zenith-angles on F_2-region ion-formation; (2) merging of F_1- and F_2-regions; (3) possible effect of heating. The first two will be considered now while the possible effect of heating will be treated later. It is found that the first two effects have the fundamental induced variation in the wrong phase to account for the non-seasonal variation, and furthermore that this is partially cancelled by ellipticity of the Earth's orbit.

Effect of difference in zenith-angle is illustrated in Figure 7. Here it is assumed that ion-density will vary as the square root of the zenith-angle, although the exact nature of this variation is probably not important to this discussion as will be seen. Solid lines show computed variation of ion-density, as a result of this effect, as zenith-angle changes with season. Curves A and S are then formed from these computed changes and are shown by dashed lines. As in Figure 3, the ordinate measured downward to A from the variable base-line S represents the computed ordinates with respect to the variable base-line, and the fluctuation in the base-line is the effect induced by the assumption that polar distances are equal. As a consequence S is a double-humped curve representing an induced variation which is about seven per cent higher in July than in January. This effect is in opposite phase to permit explanation of the non-seasonal term as an induced artificial effect due to treatment of data, and the amplitude is exceedingly small.

Distance from the Earth to the Sun varies because of ellipticity of the Earth's orbit, aphelion coming early in July and perihelion early in January. Thus the greatest distance coincides with the July dip of non-seasonal change. If one assumes ion-density to vary as the square root of incident energy, the amplitude of the effect can be calculated.

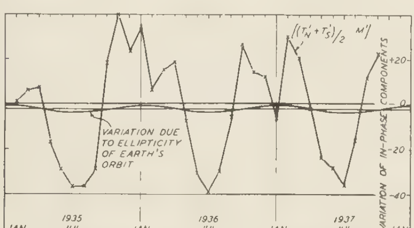


FIG. 8—RELATIVE AMPLITUDE OF IN-PHASE COMPONENTS REDUCED BY (M'/M) TO CALCULATED AMPLITUDE OF IN-PHASE TERM DUE TO ELLIPTICITY OF EARTH'S ORBIT, ASSUMING ION-DENSITY PROPORTIONAL TO RADIATION-INTENSITY

This is shown in Figure 8, where it is compared to the amplitude of term S. Though in the right direction, it is only of amplitude a little over three per cent. It is of phase such that the previous effect due to difference in latitude will be partially counterbalanced. This can be seen from Figure 7, where the amplitude of computed Washington variation will be decreased by three per cent, while that for Watheroo is correspondingly increased. As a consequence, the resultant induced effect, because of difference of polar distance and ellipticity of the Earth's orbit, is reduced to between three and four per cent, with phase in the wrong direction to account for the non-seasonal term. Thus because of

ellipticity of the orbit, the relative latitude of the stations is almost ideal for this study. Because ion-density will change in the same way with incident energy, whether it be due to change in zenith-angle or to distance, the exact form of the function of ion-density with respect to incident energy is not important to this result, provided it be of the general form indicated.

Effect of merging of the F_1- and F_2-regions is shown in Figure 9, where it is assumed that the ion-density due to F_1- and F_2-regions will

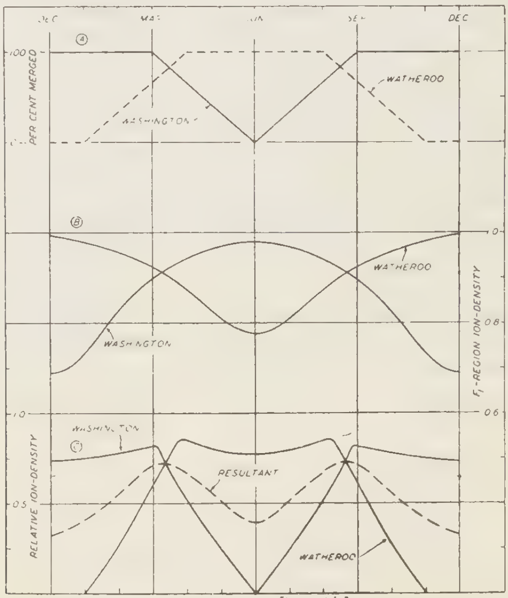


FIG. 9—RESULTANT IN-PHASE EFFECT IN $[(T_S+T_N)/2]$ DUE TO MERGING WITH F_1-REGION, ASSUMING ION-DENSITY TO VARY AS $N \propto \sqrt{\cos z}$
[JULY VALUE HIGHER THAN JANUARY VALUE BY 13 PER CENT OF WINTER F_1-REGION ION-DENSITY DUE TO LATITUDE-DIFFERENCE, RESULTANT EQUINOXIAL VALUES DEPEND ON CONDITIONS ASSUMED FOR MERGING]

add as the regions merge*. For the conditions shown in Figure 9, curve S will be about 13 per cent of the winter F_1-region ion-density higher in July than in January, due to the effect induced by treatment of the data. This also will be reduced about three per cent due to ellipticity of the Earth's orbit to about ten per cent. Near the equinoxes, humps of about 50 per cent of the winter value of F_1-region ion-density occur due to merging, though these values can be changed very considerably by the assumptions. The F_1-region ion-density at winter noon is from one-third to one-sixth of the F_2-region ion-density, so that the change in the latter would be about two or three per cent more in July, and perhaps

*The assumption of merging in this form implicity involves a material decrease in ion-density between the regions F_1 and F_2 when they are widely separated. This may not be the case, for there is theoretical reason to believe that the ion-density above the height of maximum of F_1-region, due to the ionizing process producing F_1-region, will remain nearly constant with height until limited by complete ionization. In such event, the correction for merging would be decreased or eliminated. The assumption of merging is made, however, as the limiting correction which can be applied because of such causes.

ten or twelve per cent more near the equinoxes, than in January, as determined on curve S. Again the effect is in the wrong phase to explain the non-seasonal change as an effect produced by the treatment of data. The double humps are of form such as to appear principally as second-harmonic seasonal terms as we have seen.

Error because of inhomogeneity of data has already been mentioned and must now be considered. Suppose a difference from the true mean of ϵ exists in the monthly mean of one station. Then the observed values of A and S become

$$\left.\begin{aligned} A_0 &= (T_N+\epsilon-T_S)/2=(T_N-T_S)/2+(\epsilon/2) \\ S_0 &= (T_N+\epsilon+T_S)/2=(T_N+T_S)/2+(\epsilon/2) \end{aligned}\right\}$$

Thus half the error will appear in A and half in S. In general, positive errors in either T_S or T_N push the curves of S' of Figure 5 outward. Negative errors in T_N or positive errors in T_S push the curve for $+A$ upward. The effect of differences from the true mean is summarized in Table 4.

TABLE 4—*Effect of differences between the true and observed means on curves of Figures 3, 4, and 5 due to inhomogeneity of data*

Observed values at	Error	Curve of S	Curve of $+A$
Washington above true mean . . .	$+\epsilon_N$	Out (up for top curve)	Down
Watheroo above true mean	$+\epsilon_S$	Out (up for top curve)	Up
Washington below true mean . . .	$-\epsilon_N$	In (down for top curve)	Up
Watheroo below true mean	$-\epsilon_N$	In (down for top curve)	Down

Thus in Figure 5, for example, an error of $+\epsilon$ will cause the point to appear farther out on curves S and down on curve A by an amount $(\epsilon_N/2)$ (M'/M). If an error $+\delta$ occurs at one station, and $+(\delta+\epsilon)$ at the other, the curve for S is pushed outward by an amount δ in addition to the correction of $\epsilon/2$ given above. Likewise if an error $-\delta$ occurs at one station and $+(\delta+\epsilon)$ at the other, the curve for A will be appropriately changed by an amount δ in addition to the correction due to $\epsilon/2$ given in Table 4. To produce the in-phase effect by errors due to inhomogeneity of data, both stations would involve differences from the mean of always $+\epsilon=(S-M)$ in the months around January, and $-\epsilon=(M-S)$ in the months around July. While such a situation is exceedingly improbable except through natural weighting which would in itself require special explanation, actual differences from the true mean are probably sufficient that a quantitative harmonic analysis of the data over such a short period is not justified.

When observations are made on only part of the days of each month, chance distribution of ionospheric disturbances because of magnetic storms or other effects may distort the monthly mean at one or both stations. One would suppose that this would balance out over any extended period, but the effect may be naturally weighted toward a particular season in even perfectly continuous data for the following reason. There is some evidence to indicate that magnetic disturbances affect noon-values of F_2 critical frequency more greatly in summer than in

winter. Thus an error of $-\epsilon_N$ might occur at Washington most frequently near June, and of $-\epsilon_S$ at Watheroo most frequently near December. This is supported somewhat by Figure 10 where maximum and

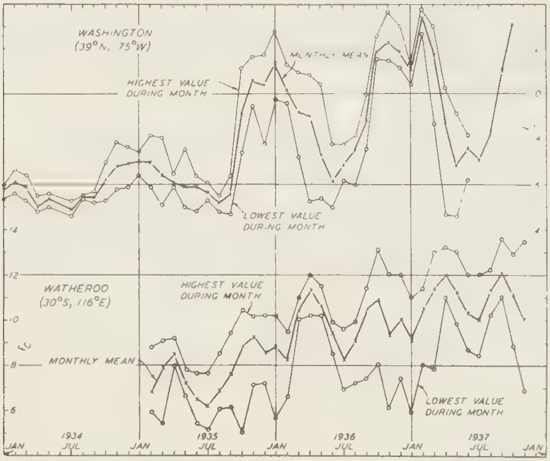


FIG. 10—RANGE OF MONTHLY MAXIMUM TO MINIMUM VALUE WITH RESPECT TO MONTHLY MEANS

minimum monthly values of critical frequency are plotted around the curve of monthly means. Percentage range is generally greater in local summer. This effect cannot have produced the July dip in the curve S because (1) the range indicates that the mean has not been materially affected and (2) the curve of maximum values follows monthly means very closely, so that the mean is not unduly distorted by disturbed or abnormal values. The July dip at Watheroo is apparent in maximum values as well as in means. Some of the individual points on curves S or A which seem out of line, as in January 1937, may have been induced by differences from the mean of this sort.

It has been suggested that the in-phase effect may be produced in whole or in part by changes in sunspot-activity, or that an artificial effect might be produced by the rapid change of ion-density with rise in the sunspot-number. Change in annual mean F_2-region ion-density with sunspot-number is well known. Figure 11 illustrates the correlation between annual means of ion-density and sunspot-numbers over the last four years. It is found to be almost perfectly linear over this interval, following the approximate relation

$$\overline{N} = (3.7 + 1.1\overline{R})\ 10^5 \sqrt{\cos z} \qquad (16)$$

Monthly means of ion-density, $S = [(T_N + T_S)/2]$, are similarly plotted against monthly mean values of sunspot-number in Figure 12. Means for months between January and April and October and December are indicated differently from means for months between May

2—CORRELATION OF MONTHLY AVERAGE OF ION-DENSITY WASHINGTON AND WATHEROO $[(T_N + T_S)/2]$ WITH MONTHLY MEAN OF SUNSPOT-NUMBERS

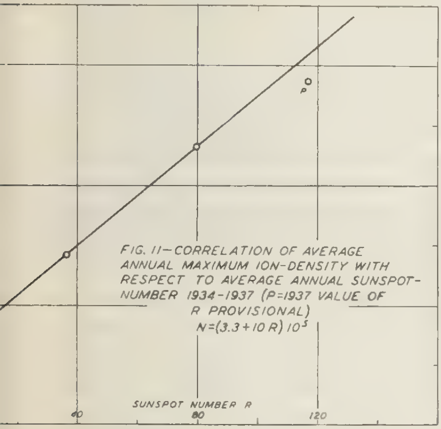
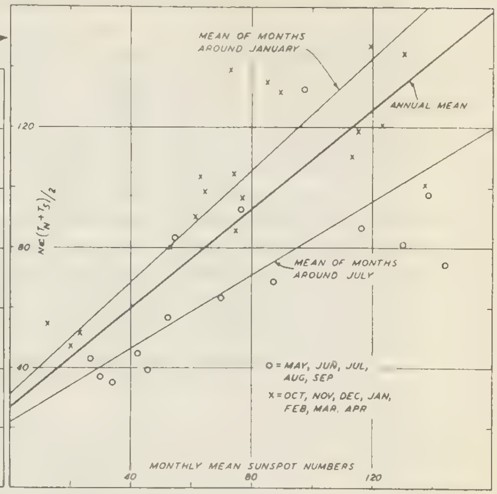


FIG. 11—CORRELATION OF AVERAGE ANNUAL MAXIMUM ION-DENSITY WITH RESPECT TO AVERAGE ANNUAL SUNSPOT-NUMBER 1934-1937 (P=1937 VALUE OF R PROVISIONAL)
$N=(3.3+10\,R)\,10^5$



and September. Almost without exception, means for months about July fall below the line of annual means, while those for months around January lie above it. Because of the scatter of points in Figure 12 there is a strong suggestion that the correlation does not hold for fluctuations around the mean, and that the apparent correlation appears because of the strong annual correlation which weights the points. Because the curve M through the annual means is linearly related to annual sunspot-means, one can draw the same curve through a graph of mean monthly sunspot-numbers by the use of (16), so that the same reference exists for both. Departures of monthly means of sunspots and of ion-density

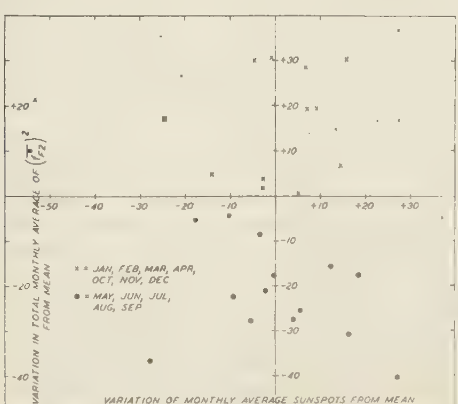


FIG 13—CORRELATION OF DEPARTURES FROM MEAN CURVE M OF MONTHLY MEANS OF ION-DENSITY AND SUNSPOT-NUMBERS

can then be obtained from this common line of reference. This is done in Figure 13, where the abcissa is the departure of monthly sunspot-number from the reference, while the ordinate is departure of ion-density, S, from line of reference, M. Clearly, no very appreciable correlation exists between fluctuations around the mean of monthly sunspot-numbers and ion-density. Points fall in almost equal numbers in all quadrants. As in Figure 12, values for months around January are almost without exception above the mean, and for months around July below the mean, but there is no tendency for low values coming around July to correspond consistently with low sunspot-numbers. Instead, correspondence with low sunspot-numbers is about as good around January as around July, the same being true of correspondence to high sunspot-number. We conclude that fluctuation of monthly means of ion-density around the line of annual means is sensibly independent of sunspot-variation as measured by monthly means.

The meaning of the shift of line of correlation with time of year can be best seen from Figure 14. Here means of the months from January

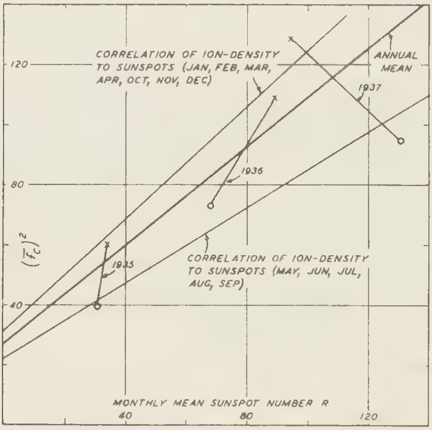


FIG 14—CHANGE OF RELATION OF SUNSPOT-NUMBERS TO MAXIMUM ION-DENSITY WITH TIME OF YEAR

to April and October to December and from May to September are plotted separately. In this way lower order even-harmonic seasonal effects are effectively removed from the data. There appears to be no relation between directions of lines through values for each year as might be expected when no correlation exists between monthly fluctuation of ion-density and sunspot-number. At the same time, shift of the relation between sunspots and ion-density with time of year is apparent. This is simply caused by the fluctuation of ion-density, independent of sunspot-changes, of a period of about one year, and of amplitude proportional to annual average ion-density. As was seen from Figure 5, the average for months around January is always higher than the average around July, and we see that this is without regard to fluctuation of sunspot-numbers from the mean during this time. We conclude there-

fore that the non-seasonal fluctuation is not induced by short period sunspot-fluctuations. It is an independent effect. As a consequence it is not permissible to correct individual monthly values of ion-density by use of corresponding monthly sunspot-averages.

In discussing possible effects of heating and expansion of the outer atmosphere on F_2-region ion-density, the wider aspects of the whole problem must be considered. From the upper curve of Figure 2 it is seen that maximum ion-density at Washington is reached in the winter, the minimum coming about June or July. This is inversely proportional to a function in cos z. Hypotheses have been proposed by Appleton and Naismith [5], by Hulburt [6], by Harang [7], and others which explain this effect by supposing that the outer atmosphere will heat and expand under the Sun's more direct rays. In the theory of Appleton and Naismith, the ratio of ion-density from summer to winter is given by

$$N_S/N_W = \sqrt{[\sin(\theta+\delta)/\sin(\theta-\delta)]\,(T_W/T_S)^{1/2}} \qquad (17)$$

where θ is the polar distance, δ is the declination, and (T_W/T_S) is the ratio of winter to summer temperature and where the electronic and molecular temperatures are assumed proportional. Applying this to the Washington data, the ratio of summer to winter temperature is of the order of $(T_S/T_W) = 300$ with considerable dependence upon interpretation of the data. Now at Watheroo, because of the much smaller fluctuation already discussed, this ratio is $(T_S/T_W) = 2$. It turns out that the rise of temperature at Washington would be more than 100 times that at Watheroo, a value which does not appear reasonable.

If we remove the non-seasonal quantity W from both stations, and compute the rise of temperature from the seasonal variation, V, this ratio becomes $(T_S/T_W) = 10$, which is equally applicable to both stations. With the assumption that non-seasonal variation is a separate phenomenon, one thus arrives at a value of rise of temperature which is perhaps not unreasonable. While we are not entirely convinced of the correctness of the heating hypothesis in its present form on the grounds of other discrepancies which cannot be discussed here, it must be said that with the correction for non-seasonal effect, it is at present the only explanation which quantitatively accounts for the remaining midsummer dip. It is clear that unless one be permitted to make a correction of the form indicated, he will arrive at unreasonable ratios of rise of temperature between the two stations.

In summing up the foregoing, there is found a non-seasonal fluctuation of ion-density at Washington and Watheroo which has a principal period that is indistinguishable from one year and an amplitude about equal to that of the seasonal variation. The amplitude appears to maintain an approximately fixed ratio to the average background ion-density. The effect cannot be explained by the difference of latitude of the two stations from the equator, nor by the ellipticity of the Earth's orbit on the basis of existing theoretical notions—in fact the two effects partially counterbalance each other so that the stations are almost ideally located for this study. The effect of inhomogeneity of data, and especially the result of natural weighting because of magnetic and other disturbances, cannot account for this non-seasonal fluctuation. While

the correlation between annual sunspot-variation and annual mean ion-density is very close over the interval studied, there is no correspondence between fluctuations of ion-density around the mean and corresponding monthly variations of sunspot-number around the mean. The effect cannot be so explained, nor is correction of the data by monthly sunspot-number permissible. If the data of the two stations be corrected for the non-seasonal effect, a consistent answer for heating ratios can be obtained.

We must see what can be determined concerning the generality of the effect. We first investigate the probable contribution of surface-conditions, such as the relative distribution of the masses of land and water with respect to a station as proposed by Goodall [8]. As has been shown, contributions which are unique at one station, as might occur because of surface-influence, would appear in both curves S and A. We recall that variations of E- and F_1-regions in daylight, and with season, yield to a theory based upon variation of local zenith-angle alone, without any resort to surface-conditions. The E- and F_1-regions are interposed between the F_2-region and the Earth, so that we are inclined to doubt seriously that surface conditions can have a very sensible effect on the F_2-region.

An opportunity to test experimentally, not only this point, but the generality of the non-seasonal effect, lies in investigation of data of other stations. If the effect proves general, it would preclude an explanation in terms of local surface conditions. We have examined data from Tromsö [9], London [10], and Tokyo [11, 12] in the Northern Hemisphere, and from Huancayo [1, 13, 14] in the Southern Hemisphere. In every case, during periods of appreciable sunspot-activity* there is a major dip in the July data for noon-values of F_2-region critical frequency without regard to the hemisphere in which the station is located. This means that if the data from any Northern Hemisphere station is combined with the data from either station in the Southern Hemisphere, as has been done here, a non-seasonal term appears. This non-seasonal variation is in *the same phase as that derived from the Washington-Watheroo data.*

As a consequence of this agreement among the data of existing stations, there seems no reason to believe that the effect is not a general one, though the amplitude may vary significantly from one location to another upon closer analyses of the available information. So far as we are aware, there is at the present time insufficient data from other locations to permit analysis for a second pair of stations in the way herein described. When reasonably continuous data become available from two pairs of stations in the two hemispheres, many of the uncertainties discussed can be eliminated by analytical methods involving all four stations. Thus for example differences from the true mean can be largely detected, the significance of small superimposed fluctuations which are seen on the graphs can be determined, and the whole effect much more clearly defined.

Whether the effect can be expected to continue with the same phase and amplitude in the future depends, of course, upon the source. The Washington data extend back about seven years, and the July dip has

*It is necessary to make this restriction, for when the Sun is quiescent during sunspot-minima, the ion-density of the F_2-region falls below that of the F_1-region on an appreciable number of days. Comparisons during such periods are not exact because maximum ion-density of F_1-region is the limiting quantity.

always been as prominent as in the data presented (with the possible exception of the year of sunspot-minimum). There is no *a priori* reason to believe, therefore, that the general nature of the variations at Watheroo was any different during this period just preceding, than during the present interval. This extends the time-interval upon which prediction could be based, and from which the major period can be determined, bringing this period very close to one year. Therefore the accumulated evidence indicates that the effect has been a regular one over several years and is, in fact, an annual one. On the basis of the facts set forth, we are inclined to believe the effect to be a general one associated with the Earth or its motion.

As regards the source of the effect, we are unable to make any definite suggestion. The ionizing source (or sources) of the F_2-region is not definitely known, so there remain such terrestrial possibilities as the varying position of the Earth's magnetic moment with respect to the Sun, the changing direction of the Earth in its orbit, etc. The effect of circulation in the high atmosphere under the influence of the Earth's magnetic field might also be considered. The paucity of observations at other hours, especially at night, precludes the isolation of other singularities which might be immediately related to the effect, for example, as might be associated with sidereal causes. We may point out that there are other F_2-region effects which have not yet been satisfactorily explained. The character of the diurnal variation at Washington and Watheroo is not the same in corresponding seasons. Thus while the F_2 critical frequencies at Watheroo reach their maxima near noon, or very shortly thereafter, in midsummer, those at Washington have a tendency to reach maxima late in the afternoon in midsummer. In fact, this noon "bite-out" in 1935 occurred at both stations markedly only in the months around July. While the non-seasonal effect here discussed cannot be explained simply by a shift in the time of maximum as far as we can now determine, because of the amplitudes involved, it appears likely that the bite-out phenomenon may be related in part at least with the non-seasonal change. Such relations and singularities can only be isolated with reliable observation through the 24 hours.

While one may hesitate to accept with finality the generality of the non-seasonal effect on the meager available data, there is one point which is unambiguous. It is not permissible to make quantitative calculations of seasonal effect of a general nature on data from a station in one hemisphere alone. Neither can one predict the variation in one hemisphere from that in the other, on the basis of the present hypotheses, without regard to non-seasonal effect.

We wish to express our appreciation to Dr. J. A. Fleming, whose active support made possible establishment of facilities for ionospheric research in the Southern Hemisphere by the Department of Terrestrial Magnetism, Carnegie Institution of Washington, to the staff of the Radio Section of the National Bureau of Standards who, through prompt publication, have made available their long series of data, and to our colleagues for their helpful discussion and suggestions. In particular we are indebted to Dr. H. G. Booker and S. E. Forbush for their critical examination of the methods used, and to S. L. Seaton and T. K. Hogan who are responsible for the excellent series of observations from Watheroo.

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Washington, D. C., January 15, 1938

IONOSPHERIC OBSERVATIONS: ECLIPSE OF JUNE 8, 1937

By H. W. Wells, H. E. Stanton, and S. L. Seaton

Abstract—Special ionospheric observations conducted at Huancayo (Peru) and Watheroo (Western Australia) for the eclipse of June 8, 1937 show:

(1) The day of the eclipse was normal, ionospherically.

(2) No eclipse-effect for *F*-region critical frequencies at Huancayo.

(3) The eclipse caused merging of the F_1- and F_2-regions, followed by normal conditions at sunset, more than an hour earlier than usual.

The absence of any eclipse-effect in the *F*-region critical frequencies may be real or may be attributed to the fact that the eclipse did not occur at Huancayo until late afternoon. It is suggested that for such conditions ionizing radiation from the Sun would be greatly reduced by absorption in the Earth's atmosphere before the beginning of the eclipse due to the large zenith-angle of the Sun.

A special program of ionospheric observations was conducted by the Department of Terrestrial Magnetism, Carnegie Institution of Washington, at Huancayo, Peru (12° 02′.7 south, 75° 20′.4 west) and at Watheroo, Western Australia (30° 19′.1 south, 115° 52′.6 east) for the purpose of studying the effect of the solar eclipse of June 8, 1937 upon the ionosphere. Although the eclipse was not visible at Watheroo,

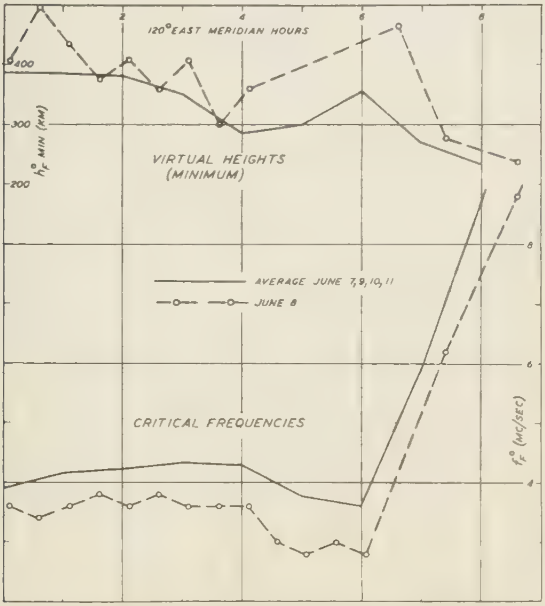

FIG. 1—F-REGION CRITICAL FREQUENCIES AND VIRTUAL HEIGHTS (MINIMUM) FOR "O" WAVE-COMPONENT, WATHEROO MAGNETIC OBSERVATORY, JUNE 1937

observations there serve to determine the general nature of the eclipse-day in comparison with control days. At Huancayo the eclipse began at $16^h\ 21^m$ (75° west meridian time), reached a maximum of about 98 per cent totality at $17^h\ 21^m$, and ended at $18^h\ 17^m$, which is after sunset at the ground but before sunset at heights of upper regions of the ionosphere. In this report we limit our discussion to the F_2- or F-regions since it has been established already that the ionization of E- and F_1-regions is due principally to ultra-violet radiation [see 1, 2, 3, 4 under "References" at end of paper] and since the time of eclipse at Huancayo was unfavorable for precise determination of any eclipse-effect upon lower ionospheric regions.

Results obtained at Watheroo are shown in Figure 1. It compares critical frequencies (f^o_F) on the eclipse-day, June 8, with the mean for the control-days, June 7, 9, 10, 11. The values on June 8 run consistently lower than the average but the deviation from the mean is of approximately the same magnitude as variations found on some control-days, and the general shape of the graphs is the same. Minimum virtual heights (h^o_F min) recorded on June 8 are compared with control observations in Figure 1. The F-region heights on June 8 were generally higher than the average but again the trend is similar and the deviation is of the same order as control-day variations. These comparisons indicate that the ionosphere at Watheroo was not abnormal or disturbed. Since ionospheric disturbances have been shown to be widespread in nature, we may assume that the ionosphere in other parts of the world was normal, as well.

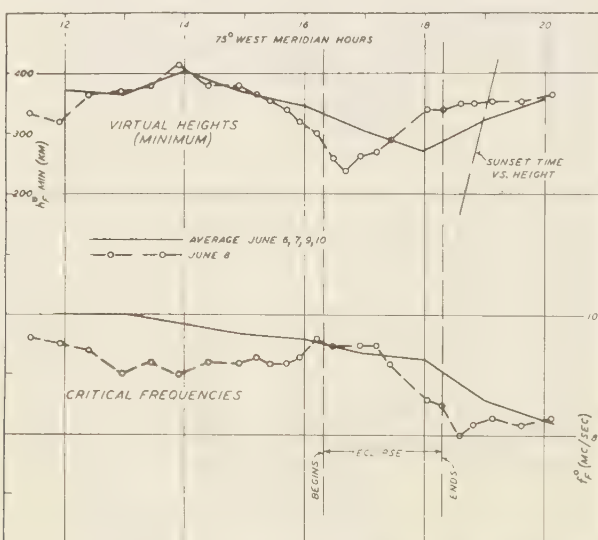

FIG 2—F-REGION CRITICAL FREQUENCIES, VIRTUAL HEIGHTS (MINIMUM) FOR "O" WAVE-COMPONENT, HUANCAYO MAGNETIC OBSERVATORY, JUNE 1937

Eclipse-observations at Huancayo are compared with control-data in Figure 2. Critical frequencies (f°_F) and minimum virtual heights (h°_F min) are shown in Figure 2[1]. The average f°_F for the control-days, June 6, 7, 9, 10, shows a smooth trend to lower values from noon. The values on June 8 of f°_F were lower than the average until just before the beginning of the eclipse. During the first half of the eclipse-period the values of f°_F on June 8 were practically coincident with the control data, and during the latter half of the eclipse-period these values dropped below the average but, as was the case for Watheroo, the deviation from the mean is of the same order as the normal range for some control-days. It is therefore apparent that for the special conditions existing at Huancayo there was no unusual change of ion-density in the upper ionosphere. This deduction is further substantiated by the fact that the same downward trend continued for a short period after the ending of the eclipse (which was still before F-region sunset), thereby indicating that the below-average values during the latter part of the eclipse-period may not be attributed to masking of the normal ionizing agency by the Moon.

The curves of (h°_F min) show a rapid decrease in h after the beginning of the eclipse which is associated with the merging of F_1- and F_2-regions to form the F-region. This is followed by a gradual increase during the rest of the eclipse-period. It is seen that the general shape of the curves is the same but the graph for June 8 is shifted over an hour earlier. An effect of the eclipse therefore was to produce normal sunset-conditions associated with merging of the F_1- and F_2-regions approximately 25 minutes after the beginning of eclipse. That the curve was normal after the ending of eclipse is explainable by the fact that the eclipse-ending did not occur until after merging usually takes place as indicated by the minimum at 18^h in the control-curve.

These considerations lead to the conclusions:

(1) June 8 was normal ionospherically.

(2) The eclipse did not affect appreciably F-region critical frequencies at Huancayo.

(3) The eclipse caused merging of the F_1- and F_2-regions, followed by normal conditions at sunset, more than an hour earlier than usual.

Conclusion (2), however, must not be taken as a statement that a solar-eclipse does not affect f_F. The observation agrees with the results of Kirby, Berkner, Gilliland, and Norton [1] in 1932 but disagrees with later results by Kirby, Gilliland, and Judson [4] and Naismith [5]. (The former observation was made in summer which corresponds more nearly to our observations.) In considering these results one must bear in mind that the eclipse started late in the afternoon and ended after ground-sunset, resulting in a large angle of incidence of the shadow. It is therefore possible that any ionizing radiation from the Sun may have been effectively absorbed in the Earth's atmosphere before the beginning of eclipse. Only a relatively small amount of ionospheric data for eclipses has been obtained. Additional eclipse-data, recorded preferably with automatic multifrequency ionospheric apparatus, are urgently needed in order to determine the true effect of a solar eclipse upon ionization in the upper atmosphere.

[1]These curves actually include values for both F_2- and F-regions; for simplicity of designation we use only f°_F.

We wish to express appreciation to Dr. J. A. Fleming under whose direction this program has been conducted, and to Messrs. L. V. Berkner and F. T. Davies for assistance with the observations and consideration of results.

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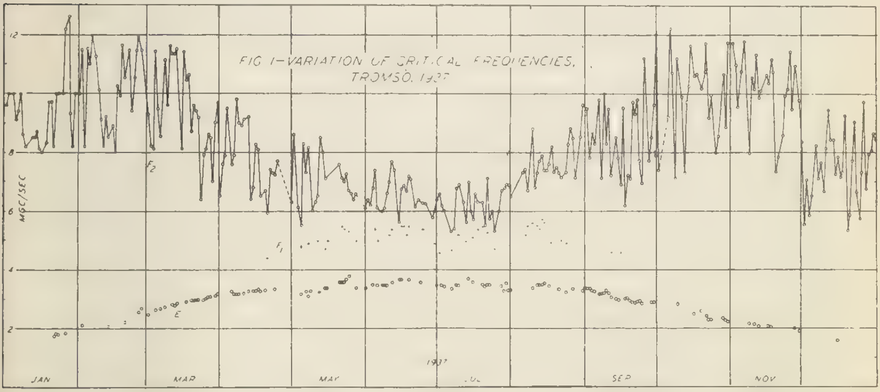
ANNUAL VARIATION OF THE CRITICAL FREQUENCIES OF THE IONIZED LAYERS AT TROMSÖ DURING 1937

By Leiv Harang

Daily measurements of the critical frequencies, the results of which up to September 1936 are given in a previous paper[1], were continued during 1937. Regular observations were usually taken on six days during the week at 10^h, 12^h, 14^h, and 18^h, local time. At Tromsö, a station subject to much magnetic disturbance, the echoes during disturbed periods appear very irregularly and are often lacking during the most intense phase of the Earth's magnetic or auroral activity. Figure 1 shows the variation of the critical frequencies for the F_2-, F_1-, and E-layers during 1937. The critical frequencies for the F_1-layer are developed only during the four summer months. During the period when the Sun is below the horizon in winter we do not obtain E-echoes during undisturbed conditions.



In Table 1 the monthly mean values of the critical frequencies are given. For the sake of completeness the values, not included in the previous communication, during the period October to December 1936 also are given.

Compared with 1935 and 1936, the values of the critical frequencies during 1937 show a continuous increase for all layers, it being most pronounced for the F_2-layer. A survey of the annual variations of the critical frequencies during the last three years determined by aid of the mean monthly values is given in Figure 2.

[1]Terr. Mag., 42, 55-72 (1937). In Pub. Inst. Kosm. Fysikk, Nr. 11 (1937), Results of radio-echo observations for the years 1935 and 1936, a detailed account of the results of the daily observations at the Auroral Observatory, Tromsö, is given; a similar report will appear each year.

Table 1—*Monthly mean values of critical frequencies in megacycles per second, ordinary component only, Tromsö (latitude 69°.66 north, longitude 18°.95 east), October 1936 to December 1937*

Month	Region and local time								
	E			F_1			F_2		
	10^h	12^h	14^h	10^h	12^h	14^h	10^h	12^h	14^h
1936									
October	2.46	2.59	2.47	....	....	....	8.98	9.61	9.90
November	1.82	1.93	1.88	....	....	....	7.69	9.42	8.51
December	....	....	....	....	....	....	6.13	8.52	8.23
1937									
January	(1.83)	(1.91)	....	....	....	....	6.93	9.47	8.30
February	2.12	2.31	2.16	....	....	....	9.18	10.26	9.62
March	2.74	2.92	2.71	....	....	....	8.79	9.50	10.07
April	3.05	3.28	3.10	....	....	....	7.77	7.80	7.60
May	3.31	3.45	3.43	4.95	5.03	4.86	7.05	7.04	6.86
June	3.51	3.57	3.56	5.23	5.27	5.27	6.55	6.63	6.45
July	3.44	3.47	3.45	4.96	5.05	5.05	6.34	6.28	6.25
August	3.33	3.40	3.35	5.24	5.33	5.44	7.81	7.74	7.68
September	2.97	3.07	2.95	....	....	....	8.22	8.58	8.27
October	2.58	2.43	2.41	....	....	....	9.42	10.33	8.94
November	2.05	2.09	2.00	....	....	....	8.39	10.25	9.50
December	....	....	....	....	....	....	6.38	7.94	6.75

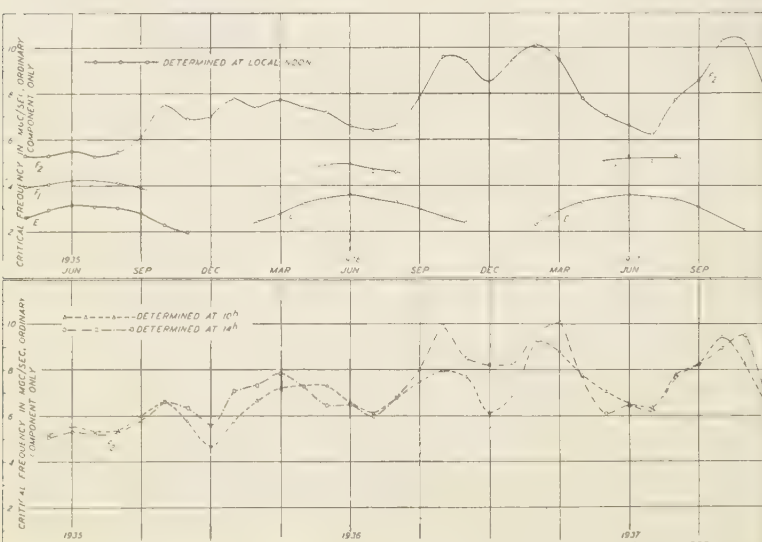


FIG. 2—MEAN MONTHLY VALUES OF CRITICAL FREQUENCIES, TROMSÖ, 1935-37

The general course of the annual curves of the critical frequencies for the layers is the same as previously stated for the Northern Hemisphere, with high values of the critical frequencies for the E- and F_1-layers during summer and low values during winter, whereas the F_2-layer shows an inverse annual variation. The continuous increase of the critical frequencies during this period of increased solar and magnetic activity also seems to be generally observed, as has been previously noted[2].

It now seems to be a well-established opinion that the primary cause for the formation of the ionized layers is the action of the ultra-violet light on the upper atmosphere. Physically the increase in ionization of the layers must be ascribed to an increase of the ultra-violet radiation from the Sun. As Edison Pettit[3] has demonstrated, a close relation exists between sunspot-numbers and the amount of ultra-violet light emitted from the Sun, the amount of ultra-violet radiation increasing during periods of great solar activity.

[2]S. S. Kirby, L. V. Berkner, and D. M. Stuart, Proc. Inst. Radio Eng., 22, 481-521 (1934).

[3]Third report of the Commission Appointed to Further the Study of Solar and Terrestrial Relationships, 105-106 (1931).

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REVIEWS AND ABSTRACTS

APPLETON, E. V.: *Regularities and irregularities in the ionosphere.* London, Proc. R. Soc. A, v. 162, 1937 (451-479).

Selected topics from the information derived from radio sounding of the ionosphere are discussed and considered in connection with results derived from a theory of simple layer-formation by solar ionizing radiation, traveling rectilinearly and attenuated according to a mass-absorption law. The comparisons are concerned chiefly with the variation of maximum electron-content with the angle of incidence of solar radiation, with the total electric conductivity for direct currents such as determines the quiet-day magnetic variations, and with the absorption of high-frequency radio waves traversing such a simple layer, the last two quantities being to some extent related.

It is deduced from Chapman's theory of layer-formation that in southeast England the height of maximum ion-production increases from summer noon to winter noon by $1 \cdot 23\ H$, where H is the scale height for the region in question. Expressions are deduced for the total conductivity of a simple region for steady electromotive forces acting at right-angles to the magnetic meridian, and this is related to the integrated absorption-coefficient of the layer for radio waves of frequency sufficiently high to pass through the layer without suffering appreciable deviation. It is shown that, provided the collisional frequency is small compared with the electric-wave frequency, the level of maximum absorption is $1 \cdot 1\ H$ below the level of maximum ionization.

The fact that the maximum electron-content of region E is throughout the day maintained close to the equilibrium-value leads to a lower limit of 10^{-8} for the daytime recombination-coefficient in this region. This is greater than the values (of the order of 2×10^{-9}) found for night-time conditions, so that there appears to be a marked increase in the value of the effective electronic recombination-coefficient from night to day.

A diagram is drawn of the variation during the years 1935 and 1936 of the monthly averages of the noon reflection-coefficients of the ionosphere for radio waves having a frequency of four mc per sec, intermediate between the critical penetration-frequencies of regions E and F. The results are explicable in a general way in terms of an absorbing layer which is more densely ionized in summer than in winter. The ratio of the values in summer and winter of the logarithm of the reflection-coefficient is found to be about $2 \cdot 6$. In view of the fact that the quiet-day magnetic variation is also two or three times as

large in summer as in winter, this suggests that the magnetic currents flow in the lower part of the ionosphere.

The electron-conductivity of region E for steady electromotive forces at right-angles to the magnetic meridian is found to be about 8×10^4 times smaller than the conductivity of 9×10^{15} esu deduced by Schuster and Chapman from their studies of terrestrial magnetism. A way out of this difficulty is to assume that there are in region E, undeducted by radio methods, considerable quantities of negative ions which contribute substantially to the direct-current conductivity. The ratio of the number of ions to the number of electrons required will be from 10 to 10^3. The presence of negative ions in region E would increase the effective electronic recombination-coefficient by roughly the ratio of the negative-ion concentration to the electronic concentration. The fact that the effective electronic recombination-coefficient in region E is greater during the day than during the night is thus probably due to the greater value of this ratio in the daytime.

In the case of region F_2 it is possible to measure the effective value of the electronic recombination-coefficient both during the day and during the night. There is little doubt that the value found is less than that for the lower regions E and F_1. The analysis of reproduced records of the decay in nocturnal region-F ionization for the night of March 19-20, 1935 shows that the effective electronic recombination-coefficient was $2{\cdot}8\times10^{-10}$. There is a method of determining the recombination-coefficient and rate of electronic production in region F_2 during the day depending on the fact that the values of electronic density are not symmetrically developed relative to noon. The application of this method to the case of a mid-summer day and an equinox day in southeast England yields, for values of the rate of electronic production at noon, 78 and 88 electrons per cc per sec, respectively, and, for the recombination-coefficient, $8{\cdot}7\times10^{-11}$ and $8{\cdot}1\times10^{-11}$ per cc per electron per sec, respectively. It will therefore be seen that the value of the recombination-coefficient during the day is a little smaller than during the night.

The fact that region F_2 is not the location of the magnetic currents indicates that there cannot be a marked excess of ions over electrons in region F_2, and the evidence as a whole suggests that there is little or no negative-ion formation there. The fact that ions are not present in large quantities in region F_2 shows that the gas or gases there possess little electronic affinity and suggests a preponderance of nitrogen (if helium be not present). This would be in agreement with the fact that the auroral spectrum shows a greater intensity of the nitrogen band-spectrum relative to the auroral green-line at the higher auroral levels. Such a state of affairs is curious, however, since if diffusive separation does take place at these high levels there ought to be a preponderance of the lighter oxygen atoms over the heavier nitrogen molecules.

The total ion production in region F_2 is about $1{\cdot}1\times10^9$ electrons per sec per sq cm column, and in region E is not less than $6{\cdot}1\times10^8$ electrons per sec per sq cm column.

The results of fitting parabolic maxima of electronic density to observed curves showing the equivalent height of reflection of radio waves as a function of frequency leaves little doubt that the value of the scale-height H is some four or five times as large in region F as in region E, being of the order of 10 km for region E and 50 km for region F. There is, it appears, some influence at work which spreads the atmosphere out to high levels, and it is due to this influence that region F can have ionization-densities at levels of 300 km as high as a million electrons per cc. An increase in the scale height H in passing from region E to region F can be brought about by an increased temperature, or by a decreased mean molecular mass, or by a combination of these. The evidence available at present is more satisfactorily explained by the high-temperature hypothesis, but the alternative explanation in terms of a light gas such as helium cannot be rejected with certainty.

Other matters discussed are the actual height at which radio waves are reflected, and ionospheric disturbances. H. G. Booker

THE LONG PERIODIC VARIATION IN THE DIURNAL RANGE OF MAGNETIC HORIZONTAL COMPONENT AT OSLO OBSERVATORY

By K. F. Wasserfall

As is known Hansteen began in the year 1843, a series of daily variation-observations of the magnetic elements in Oslo, which have been continued uninterrupted to the present time. Some years ago the author undertook to compile the entire material left by Hansteen and his successors, pertaining to observations of the horizontal component.

The material consists of two daily observations during 1843 to 1930; the readings were taken at 9^h and at 14^h local mean time. A large magnet, 1.2 meters long and weighing 13 kg is mounted by a bifilar suspension in the vault of the central hall of the Astronomical Observatory in Oslo. A small mirror, fixed to the magnet, reflects a divided scale mounted horizontally below a telescope which rests on a marble pier in the west wing of the building.

Each observation consists of ten single elongation-readings from which a mean for the observation in question is obtained. A thermometer inside the box, which encloses the suspended magnet, supplies the corresponding temperature.

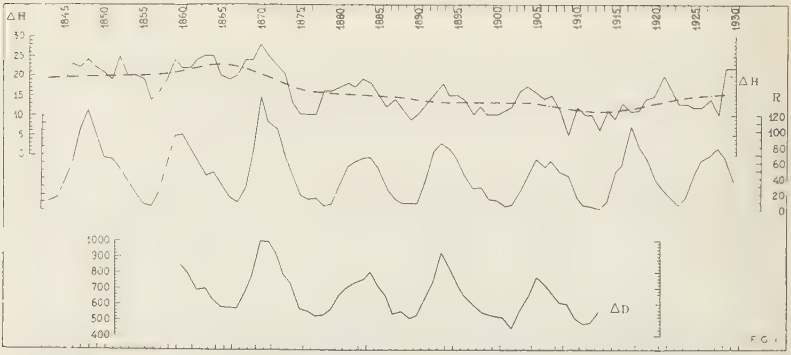
Using the available absolute observation it has been possible to determine sufficiently safe reduction-coefficients for the eye-readings of H and, during the last two years, to complete tables for the two daily readings expressed in absolute measure (CGS).

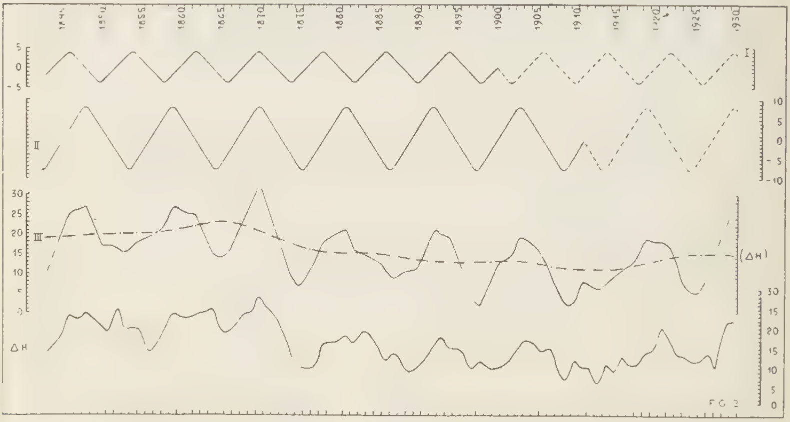
Special tables have been prepared for the daily value of the difference $\triangle H = (H_{14} - H_9)$. This difference may be taken as an expression for the diurnal range of H or, in other words, for the magnetic activity in Oslo during 1843 to 1930, and hence is of considerable interest.

Professor Wolf at Zürich published annually a corresponding quantity for the declination in Christiania (Oslo) namely, $\triangle D = (D_{14} - D_9)$ during 1883 to 1913, as comparative data for the sunspot-frequency R (cf. *Astronomische Mitteilungen*). The comparatively close parallelism of these data has always been used as a classic example for the relationship between the Earth's magnetism and solar activity.

Some time will still be required before the mass of material pertaining to the horizontal intensity at Oslo during 1843 to 1930 will be ready for publication. I have, therefore, meanwhile compiled the graphs and the monthly mean values are plotted in Figure 1 for $\triangle H$, R, and $\triangle D$. The smoothed values of $\triangle H$ are shown by the broken line.

We see that while the D-curve shows a close parallelism with that for R, the H-curve does not. A certain relation is also plainly discernible here, but the parallelism is much masked by another kind of variation. It is, however, not difficult to see that the wave-length of this other periodicity is eight years and to show that the variation of $\triangle H$ may be considered as closely related to a combined effect of a theoretically periodic undulation of eight and eleven years as shown in Figure 2. Graph I represents a regular curve of 8-year periodicity with a phase-change in 1900, while graph II represents the 11-year periodicity with a





phase-change in 1911. Graph III is the graph of smoothed values of $\triangle H$ from Figure 1 which may represent, more or less, the purely secular variation.

Now combining the three graphs I, II, and III, we obtain the curve marked ($\triangle H$) in Figure 2 below which is copied the curve of $\triangle H$ from Figure 1. As far as I can see, there can be no doubt that curve $\triangle H$ is a combined effect of an 8-year and an 11-year periodicity. I have intentionally made Figure 2 as a sketch and have not attempted to calculate the exact amplitude and other details of the two oscillation-series.

Complete tables for the quantity $(H_{14}-H_9)$ will appear in the final publication on the series in Oslo during 1843 to 1930; the data for $(D_{14}-D_9)$ have been published in *Astronomische Mitteilungen*. A complete list of monthly mean values for $(D_{14}-D_9)$ has been included in a paper by Helland-Hansen and Nansen[1].

[1]Temperature variations in the North Atlantic Ocean and in the atmosphere by B. Helland-Hansen and Fridtjof Nansen, Smithsonian Misc. Collect., **70**, No. 4, 402 (1920).

DET MAGNETISKE BYRÅ,
Bergen, October 1937

A METHOD FOR PRODUCING NON-MAGNETIC CASTINGS OF COPPER, BRASS, AND ALUMINUM

By W. F. Steiner

Abstract—A method of obtaining sound non-magnetic castings for use in magnetic measurements has been developed. This is done by a close control of the melting temperatures, a method of purification of the metal, and design of the patterns.

In the manufacture of instruments for making magnetic measurements it is essential that the susceptibility of all the materials used in their construction be negligible. In practice it is difficult to secure commercial castings for the metal parts whose susceptibility is sufficiently low. In order to standardize the method by which uniformly non-magnetic castings may be obtained, the investigation described below was carried out at the Department of Terrestrial Magnetism of the Carnegie Intitution of Washington.

There are two important details in the casting of metals which must be carried out together with the conventional methods of foundry-practice. These were developed in the experimental work carried out by C. Huff and W. F. Steiner in 1917, and are as follows: (1) The purification and pouring temperature of the metals; (2) the design of the patterns from which these castings are to be made.

Reasonable care must be given to the quality of the metal used to charge the crucibles, and during the charging of the crucible a purifying flux must be used. The flux used in the early experiments has been discontinued by the manufacturer, but it is felt that any good non-ferrous foundry flux would be adequate.[1]

During the process of heating the brass and copper it was found necessary to keep the molten metal covered with powdered charcoal to prevent excessive oxidation. To obtain a pot of metal the crucible was given three charges. Prior to each charge the flux was first added to the molten metal and thoroughly stirred and skimmed. To avoid further contamination the skimmer was made of "transite" (asbestos board) fastened to an iron rod. Throughout the melting it is important that the metal be kept at a temperature as near the melting-point as possible, and at no time should it be allowed to boil as this allows ferrous impurities to melt and flow through the non-ferrous metal. This step is the most vital detail in the process of obtaining non-magnetic castings.

The correct pouring temperatures were always controlled by the use of a pyrometer. Just before the crucible was taken from the fire a thin blanket of pure silicate sand was spread over the molten copper or brass (no sand was used on aluminum) and allowed to melt, thus forming a glassy blanket which retained the impurities floating on the surface. When pouring it will be found that this glassy blanket holding the impurities can very easily be pushed away from the spout of the crucible with the aid of the transite skimmer. Little trouble was experienced in

[1]A good flux is manufactured by the Pittsburgh Metals Purifying Corporation, Post-Office Box 6131, N. S., Pittsburgh, Pennsylvania, namely, "Ferro-outiron remover" for brass and copper; they also manufacture a suitable flux for aluminum called "Soffelite aluminum flux."

obtaining non-magnetic aluminum castings because this metal has a much lower melting-point than brass or copper, and if reasonable care is taken there is little danger that the iron impurities will flow through the metal.

The second item of importance was the design of patterns from which the castings were to be made. It must be remembered that the temperature of the metal must never be brought higher than the lowest possible pouring temperature. It is therefore necessary to design the patterns so that the mold can be filled rapidly. This is done by eliminating all very thin walls, fins, and ribs, thus allowing the molten metal to flow through and around the mold very quickly.

When the above procedure is followed, castings can be consistently made which are both sound and non-magnetic.

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THE AMERICAN MAGNETIC CHARACTER-FIGURE C_A FOR 1937

By A. G. McNish and H. F. Johnston

A new measure of magnetic activity—the American magnetic character-figure C_A—was inaugurated on March 13, 1937. As discussed in a previous paper[1] the purpose of this new measure is to supply a timely and adequate index of the Earth's magnetic condition for comparison with related phenomena, particularly radio-transmission conditions. Since its inception the American magnetic character-figure seems to have fulfilled this need. Weekly bulletins on the Earth's magnetic activity have been issued to interested persons and organizations by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington on Wednesdays, covering the seven-day interval ending at 24^h GMT the preceding Friday. More complete dissemination of the data has been accomplished by publication in the weekly bulletin of cosmic data furnished by Science Service and by quarterly publication in this Journal.[2]

The American magnetic character-figure is the mean of the assignments made to each Greenwich half-day on a scale of 0.0, 0.5, 1.0, 1.5, and 2.0 by the seven American-operated observatories at Watheroo (Western Australia) and Huancayo (Peru) of the Carnegie Institution and at Cheltenham (Maryland), Honolulu (Hawaii), San Juan (Puerto Rico), Sitka (Alaska), and Tucson (Arizona) of the United States Coast and Geodetic Survey. The character-numbers are transmitted to Washington by radio and are compiled at the central Office of the Department of Terrestrial Magnetism.

Completion of the year in which it was inagurated gives occasion for studying the measure and appraising its significance. To include a complete year in this study the records from the seven observatories for the first two and one-half months of the year were rated at the central offices of the Department and of the Coast and Geodetic Survey. Results of these ratings are given under "Letters to the Editor" together with the ratings for November and December 1937. Thus a complete year of the American character figure—730 half-days for seven observatories—becomes available for study. Only three half days from one observatory—Tucson—are lacking, due to instrumental changes. The probable assignments for these three half-days were interpolated in order that the series should be homogeneous.

To study the reliability of the American magnetic character-figure correlation-coefficients were computed between the values assigned for individual half-days by each observatory and the average values assigned by all observatories for each quarter of 1937. These coefficients appear in Table 1. The average coefficient for all observatories is 0.86, individual

Table 1—*Correlation-coefficients ratings individual observatories and American magnetic character-figure C_A, 1937*

Observatory	Jan.-Mar.	April-June	July-Sep.	Oct.-Dec.	Mean
Cheltenham	0.86	0.91	0.88	0.87	0.88
Honolulu	0.87	0.88	0.79	0.83	0.84
Huancayo	0.87	0.89	0.82	0.82	0.85
San Juan	0.84	0.61	0.69	0.92	0.76
Sitka	0.89	0.88	0.87	0.84	0.87
Tucson	0.87	0.93	0.93	0.92	0.91
Watheroo	0.91	0.84	0.88	0.89	0.88

[1] A. G. McNish and A. K. Ludy, Terr. Mag., **42**, 173-177 (1937).
[2] C. C. Ennis, Terr. Mag., **42**, 316-319 (1937); H. F. Johnston, Terr. Mag., **42**, 411-414 (1937).

values ranging from 0.61 to 0.93. Most of the values lie close to 0.90. Since ratings by individual observatories can fall in only five class-intervals while the average ratings can fall into 21 class-intervals perfect correlation is not to be expected regardless of the accuracy in judgment of the observers. The highest value which the correlation-coefficient could attain, if the half-days are uniformly distributed among the various class-intervals of C_A, is 0.985. Another factor tending to lower the correlation-coefficients is lack of linearity between the scales of magnetic activity of the individual observatories. Thus all half-days of low activity are adjudged 0.0 by Cheltenham, although the Observatory assigns the figure 2.0 as frequently as it is assigned by others.

Important information is brought out by examining the correlation-coefficient with respect to the geographical location of the observatories. Watheroo which is most isolated with respect to the other observatories has a correlation-coefficient above the average and only 0.03 less than that for Tucson which is most centrally located. This indicates that the distribution of observatories contributing to the American magnetic character-figure does not strongly prejudice its value.

In computing the correlation-coefficients statistics were evaluated from which other estimates of the reliability of the American magnetic character-figure were derived. If x_{ij} denotes the rating assigned to a given half-day by one observatory and m_i the mean of all the assignments for that day then the root-mean-square error of the rating by a single observatory is given by

$$\sqrt{\sum_{i=1}^{n}\sum_{j=1}^{N}(x_{ij}-m_i)^2/N(n-1)}$$

Table 2—*Mean magnetic character-figure assignments of individual observatories for half-days, 1937*

Observatory	Interval GMT	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Cheltenham	0^h-12^h	0.11	0.25	0.26	0.52	0.47	0.22	0.27	0.21	0.15	0.40	0.23	0.18	0.27
	12^h-24^h	0.11	0.25	0.24	0.62	0.34	0.27	0.32	0.05	0.20	0.40	0.17	0.11	0.26
	0^h-24^h	0.11	0.25	0.25	0.57	0.40	0.24	0.30	0.13	0.18	0.40	0.20	0.15	0.26
Honolulu	0^h-12^h	0.26	0.50	0.61	0.48	0.53	0.45	0.58	0.45	0.42	0.63	0.37	0.42	0.48
	12^h-24^h	0.34	0.61	0.65	0.55	0.42	0.30	0.50	0.32	0.35	0.53	0.42	0.35	0.44
	0^h-24^h	0.30	0.55	0.63	0.52	0.48	0.38	0.54	0.39	0.38	0.58	0.39	0.39	0.46
Huancayo	0^h-12^h	0.11	0.11	0.27	0.30	0.21	0.17	0.18	0.10	0.13	0.55	0.28	0.26	0.22
	12^h-24^h	0.26	0.43	0.44	0.50	0.23	0.27	0.39	0.08	0.28	0.85	0.82	0.63	0.43
	0^h-24^h	0.19	0.27	0.35	0.40	0.22	0.22	0.28	0.09	0.21	0.70	0.55	0.44	0.33
San Juan	0^h-12^h	0.16	0.41	0.24	0.25	0.11	0.12	0.18	0.23	0.23	0.55	0.23	0.16	0.24
	12^h-24^h	0.27	0.55	0.56	0.68	0.58	0.78	0.63	0.66	0.50	0.82	0.47	0.39	0.57
	0^h-24^h	0.22	0.48	0.40	0.47	0.35	0.45	0.40	0.44	0.37	0.69	0.35	0.27	0.41
Sitka	0^h-12^h	0.23	0.45	0.48	0.42	0.37	0.35	0.32	0.27	0.27	0.60	0.43	0.26	0.37
	12^h-24^h	0.26	0.55	0.44	0.42	0.24	0.27	0.29	0.15	0.23	0.52	0.52	0.31	0.35
	0^h-24^h	0.24	0.50	0.46	0.42	0.31	0.31	0.31	0.21	0.25	0.56	0.48	0.28	0.36
Tucson	0^h-12^h	0.21	0.48	0.34	0.45	0.42	0.33	0.42	0.23	0.23	0.60	0.37	0.26	0.36
	12^h-24^h	0.26	0.48	0.23	0.50	0.29	0.32	0.40	0.15	0.18	0.52	0.42	0.26	0.33
	0^h-24^h	0.23	0.48	0.28	0.48	0.35	0.32	0.41	0.19	0.21	0.56	0.39	0.26	0.35
Watheroo	0^h-12^h	0.11	0.30	0.45	0.40	0.37	0.37	0.31	0.26	0.23	0.56	0.28	0.34	0.33
	12^h-24^h	0.18	0.30	0.44	0.48	0.27	0.30	0.29	0.23	0.27	0.60	0.40	0.37	0.34
	0^h-24^h	0.15	0.30	0.44	0.44	0.32	0.33	0.30	0.24	0.25	0.58	0.34	0.35	0.34
Mean	0^h-12^h	0.17	0.36	0.38	0.40	0.35	0.29	0.32	0.25	0.24	0.56	0.31	0.27	0.32
	12^h-24^h	0.24	0.45	0.43	0.54	0.34	0.36	0.40	0.23	0.29	0.61	0.46	0.35	0.39
	0^h-24^h	0.21	0.40	0.40	0.47	0.35	0.32	0.36	0.24	0.26	0.58	0.39	0.31	0.36

in which n is the number of observatories and N is the number of half-days. The root-mean-square error of the American magnetic character-figure is this quantity divided by $\sqrt{n}$. The root-mean-square error of the individual ratings of the observatories is 0.256—approximately equal to half the rating-interval—while the error in the American magnetic character-figure is 0.0967. The class-intervals in the character-figure therefore probably represent actual differences in degree of magnetic activity. It is very unlikely that the mean rating assigned to a half-day differs by as much as 0.3 from the rating that half-day should have. Of course, in comparing relative activity of individual half-days it is important that too much significance is not attached to small differences in activity among days separated by several months. Standards of activity used in rating days appear to have changed during the year being investigated, although the change is not great.

A comparison of mean ratings for the half-days by months for the individual observatories and for the American magnetic character-figure is supplied by Table 2. A fair agreement is manifested between the activity-ratings assigned to each month by the various observatories although obvious variations in rating-standards occur. Except for Huancayo and San Juan there appears to be no great difference in the

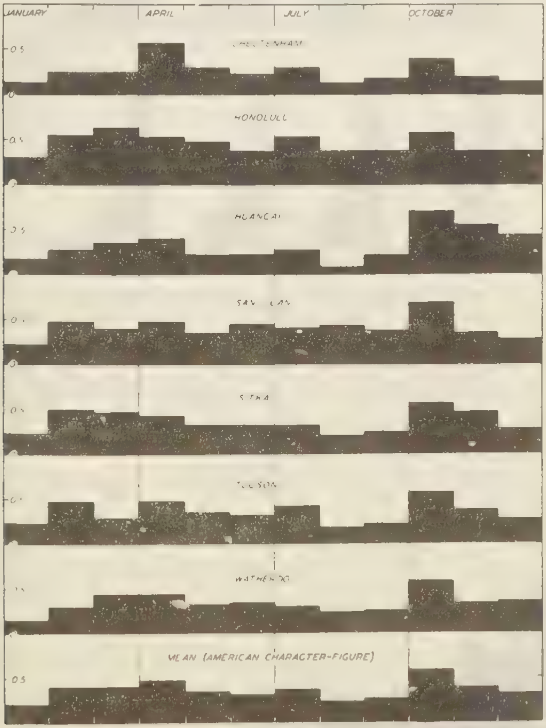

FIG. 1—MEAN HALF-DAY AMERICAN CHARACTER-FIGURES, C_A, FOR INDIVIDUAL MONTHS, 1937

activity for the two periods of the day—0^h to 12^h and 12^h to 24^h GMT. Higher character-figures were assigned to the latter half of the day by those observatories in all cases except the ratings for August at Huancayo. This probably represents a real difference in diurnal distribution of activity at those stations. All other observatories indicate a slight tendency toward greater activity during the hours of local darkness. The reporting-intervals are almost evenly distributed between darkness and light at Honolulu. Monthly mean values of the character-figures assigned at the individual observatories are shown graphically in Figure 1.

The frequency of various character assignments by the individual observatories during the year is shown in Figure 2. Half-days character-

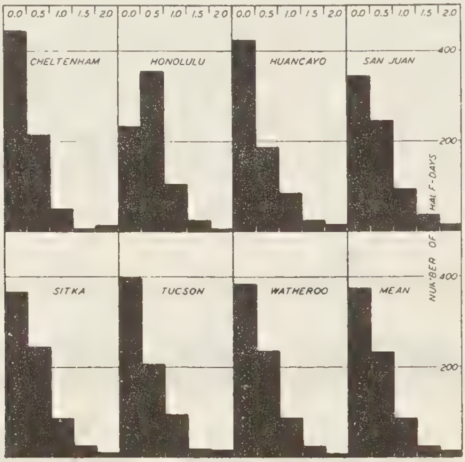

FIG 2—FREQUENCY HALF-DAY CHARACTER-ASSIGNMENTS, 1937

ized as 0.0 are most frequent for all observatories except Honolulu for which assignments of 0.5 predominate. These distributions display a clear difference in rating-standards for the various observatories. It seems that such differences are desirable. They are necessary if the various class-intervals of the American magnetic character-figure are to be significant. A corresponding distribution of the total of the ratings

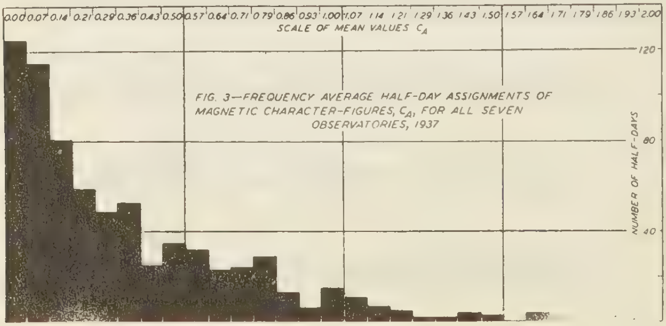

FIG. 3—FREQUENCY AVERAGE HALF-DAY ASSIGNMENTS OF MAGNETIC CHARACTER-FIGURES, C_A, FOR ALL SEVEN OBSERVATORIES, 1937

made by all seven observatories is presented in Figure 3. There are 29 class-intervals in Figure 3 instead of the 21 embraced by the American magnetic character-figure because in the process of taking means the number of class-intervals is reduced. Use of the 29 class-intervals instead of the 21 favors a more equitable distribution of half-days in the various classes.

A comparison of the American magnetic character-figure with the International magnetic character-figure for the first six months of 1937 is shown in Figure 4. Although a close relationship between the

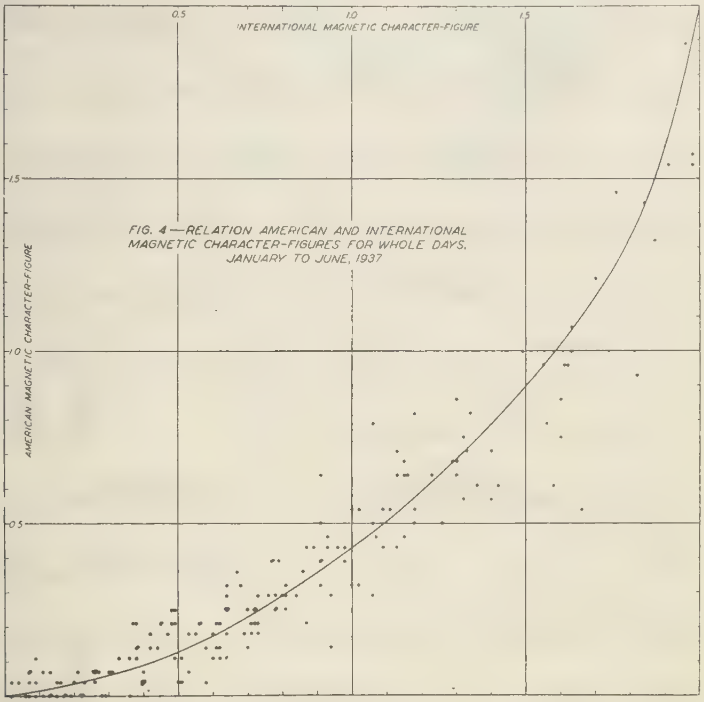

FIG. 4—RELATION AMERICAN AND INTERNATIONAL MAGNETIC CHARACTER-FIGURES FOR WHOLE DAYS. JANUARY TO JUNE, 1937

two measures is patent it is not linear. The International figure shows greater sensitiveness to variations in activity among comparatively quiet days while the American figure shows greater sensitiveness to variations among highly disturbed days. In other words, the International figure is superior for selecting extremely quiet days while the American figure is superior for selecting extremely disturbed days. During all of 1937 no half-day was rated above 1.9 on the American scale although several days of great disturbance occurred; there is still a means for indicating greater disturbance. This difference in scale of rating may make the American figure more valuable in studying correlations with other geophysical phenomena. It is particularly favorable to correlation with radio-transmission conditions which are not sensitive to low degrees of magnetic activity.

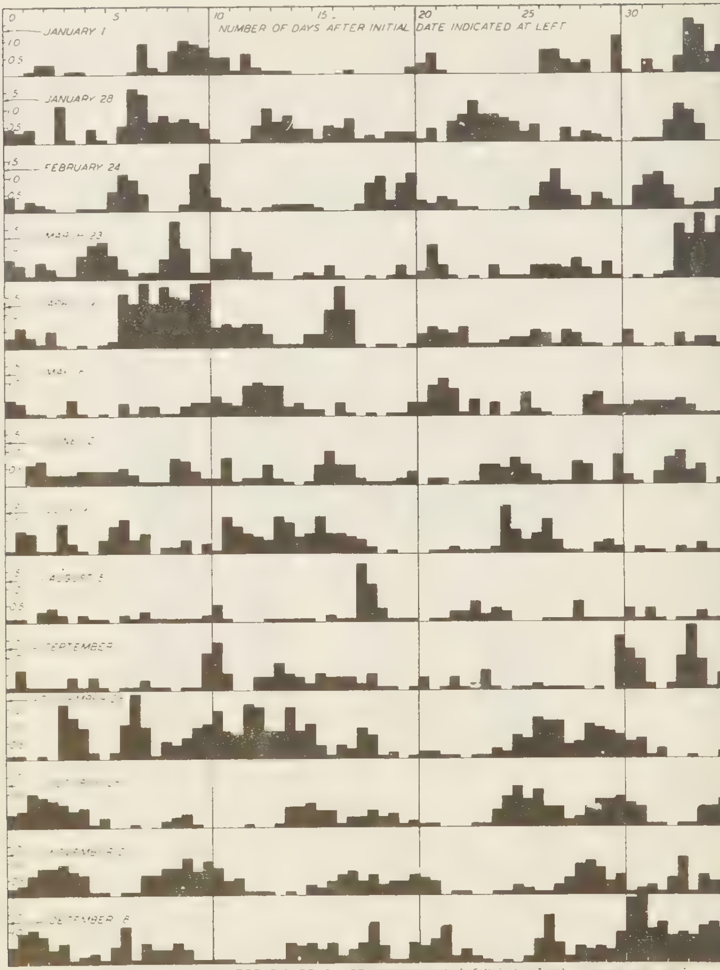

FIG. 5—AMERICAN CHARACTER-FIGURE, C_A, GR...

The American magnetic character-figure for each half-day of 1937 is plotted in Figure 5, ordered according to periods of solar rotation. The well-known tendency of magnetic disturbances to recur at 27-day intervals was not very marked during the year due to frequent outbreaks of new sequences.

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IONIZATION, NEGATIVE-ION FORMATION, AND RECOMBINATION IN THE IONOSPHERE

By Norris E. Bradbury

Abstract—The ionization in the ionosphere is discussed in the light of present theories of recombination and negative-ion formation. It is suggested that the E- and F_1-regions are formed as the result of the absorption of special bands of solar radiation and that negative-ion formation is the predominant process in these regions. A sufficient number of electrons exists, however, to cause the reflection of electromagnetic waves. The F_2-region is probably not due to the absorption of any special band of solar radiation but owes its formation to the preponderance at this elevation of electron-positive-ion recombination over negative-ion formation during the day. The characteristics of the E- and F_1-regions are discussed quantitatively and compared with experimental observations. A qualitative discussion is given for the F_2-region since it seems probable that significant changes in level and density take place at these elevations.

Recent advances in the experimental and theoretical knowledge of the properties of gaseous ions and electrons make it of interest to attempt to apply this information to probable conditions in the ionosphere. Although the excellent papers of Hulbert [see 1 of "References" at end of article] and Chapman [2] have considered the state of ionization in the upper atmosphere in some detail, it nevertheless seems of interest to consider the problem further in the light of more recent knowledge. While it is hardly to be hoped that any simple set of hypotheses at this time will adequately explain *all* the complicated phenomena which manifest themselves from time to time in ionospheric measurements, it is, however, desirable to see what is suggested by the rather excellent experimental evidence now available.

Absorption of radiation

We will assume, fundamentally, a solar source of ionization for the ionopshere. This is presumably radiation in the extreme ultra-violet portion of the solar spectrum, though exactly what radiation is necessary or what ionization-processes occur cannot be stated with certainty. This hypothesis, however, has been tested by observations during eclipses and shown to be in accord with the facts for at least the E- and F_1-layers, and may also be true for the F_2-layer. Let us assume furthermore that the band of radiation responsible for the ionization of the E-layer would undergo an exponential absorption in a uniformly dense atmosphere corresponding to an absorption-coefficient σ. Finally we will assume an atmosphere in which the particle-density undergoes an exponential decrease with height above the surface of the Earth. With these assumptions it is at once possible to derive the expressions for the ratio of the incident energy outside the atmosphere to the energy at any level above the surface of the Earth for various values of the solar altitude. Such expressions, for specific solar-altitude angles, are given below, the integrals involved having been evaluated with the sufficient accuracy by comparatively simple approximations. In general

$$\log (I/I_0) = -\sigma \int_z^\infty N(x)\mathrm{d}x$$

in which $N(x)$ expresses the particle-density along the radiation-path and z is the vertical distance above the observing point. Evaluations of expressions of this type lead to the values for $\log(I/I_0)$ given by equations (1) to (5) for solar altitudes

$$-5^\circ \quad \log(I/I_0) = -2N_0\sigma\sqrt{R+z_1'}\,\sqrt{\pi/2c}\,e^{-cz_1'} \tag{1}$$

$$0 \quad \log(I/I_0) = -N_0\sigma\sqrt{R+z_1'}\,\sqrt{\pi/2c}\,e^{-cz_1} \tag{2}$$

$$22.5 \quad \log(I/I_0) = -2.61\,(N_0\sigma/c)\,e^{-cz_1} \tag{3}$$

$$45 \quad \log(I/I_0) = -1.414\,(N_0\sigma/c)\,e^{-cz_1} \tag{4}$$

$$90 \quad \log(I/I_0) = -(N_0\sigma/c)\,e^{-cz_1} \tag{5}$$

In these expressions z_1 is the vertical elevation above the observer; z_1' is related to z_1 by the expression $(R+z_1')/(R+z_1) = \cos 5^\circ$; R is the radius of the Earth; σ is the atomic absorption-coefficient; and c and N_0 are given from the expression for particle-density as a function of elevation, $N = N_0 e^{-mgz_1/kt} = N_0 e^{-cz_1}$. Inspection of the above equations will at once indicate the general types of which they are special cases. In explanation of the inclusion of a negative angle, it may be noted that illumination of the upper regions of the atmosphere will occur before ground sunrise and remain after ground sunset, the Sun being first seen at z_1 at an angle below the horizon such that $\theta = \cos^{-1}[R/(R+z_1)]$. This amounts to a time-interval of 30 minutes to an hour for ionospheric elevations.

In order to make a definite calculation it is now necessary to make some further assumptions. Lacking definite knowledge of σ we will attempt to determine its order of magnitude from ionospheric measurements themselves. Accordingly we will calculate a value of $N_0\sigma$ on the assumption that the radiation absorbed is reduced to 0.01 of its incident value outside the atmosphere at 100 km when the solar altitude is 90°. Initially we will assume a uniform temperature in the atmosphere of 250°K and also assume uniform mixing and an average "air" molecule of molecular weight 28.8. If this is done one is led to a value of $N_0\sigma$ of 7.04. Since N_0 must be of the order of 2.5×10^{19} (the molecular density at the Earth's surface), this predicts a value of the atomic absorption-coefficient of 3×10^{-19} cm^2. Such a value is reasonable since evidence in the laboratory indicates that absorption cross-sections are of the order of 10^{-17} to 10^{-20} cm^2. However, the well-known presence of ozone in the atmosphere has led to the hypothesis that oxygen in the upper atmosphere is largely dissociated, and it is also well known that the atmosphere is thoroughly mixed at least as high as 20 km and probably somewhat higher. For present purposes, however, it will suffice to guess that the atmosphere is thoroughly mixed up to 90 km and that oxygen is dissociated beyond this level. While this hypothesis is almost certainly not in exact accord with actual conditions in the ionosphere, it is nevertheless impossible to tell at this time in just what direction the modification should be made. Accordingly the results of this distribution have been investigated, assuming as before a temperature of 250°. This of course changes the law of molecular density with elevation from that given above, and in fact gives two laws—one which must be used below 90 km and another for elevations greater than this. Fortunately the two have the same form but with different constants. With this assumption

one is led to a value of σ of 1.5×10^{-20} cm^2 which is also of reasonable order of magnitude.

It may also be pointed out that the usual assumption that the existence of layers in the ionosphere must be due to the absorption of different bands in the solar spectrum seems at least justifiable for the F_1-region. For an average height of 200 km, a law of the form suggested above would reduce incident radiation to 0.01 of its value if $\sigma = 3 \times 10^{-17}$ cm^2, which is a readily admissible value and the temperature of the upper atmosphere may well be higher than that used above.

More difficulty is experienced with the F_2-layer as the extreme rarity of the atmosphere at this level makes the complete absorption of a band of solar radiation virtually impossible unless extremely high values of upper atmospheric temperatures are assumed or values of the absorption-coefficient are orders of magnitude different from those measured in the laboratory. It is even necessary to assume the dissociation of O_2 to obtain reasonable values of the absorption-coefficient for the F_1-region.

However, we are interested fundamentally not in the actual intensity at various elevations, but in the change in the rate of absorption of the radiation with elevation since this will be directly related to the rate of ion-formation at a given height. Hence one must calculate $I(z)\sigma N(z)$ from equations (1) to (5). Curves of this function have been plotted for various solar altitudes in Figure 1, assuming $\sigma = 1.5 \times 10^{-20}$, corresponding to the value necessary to produce an E-layer. The existence of

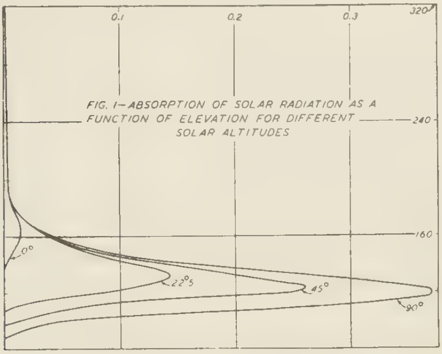

FIG. 1—ABSORPTION OF SOLAR RADIATION AS A FUNCTION OF ELEVATION FOR DIFFERENT SOLAR ALTITUDES

this type of absorption-curve has been previously shown by Chapman [2] who has developed general expressions for the rate of absorption of solar radiation in terms of the many necessary parameters. The present expressions, while less general, have the advantage of simplicity, since for any particular station, the solar altitude as a function of time of day and season, may be obtained from suitable tables.

The most conspicuous feature of these plots is the comparatively narrow region in which a very large fraction of the total incident energy is absorbed. Furthermore, the position of maximum rate of absorption is within ten km of the region where the absorption is only one-tenth as great. Hence it would be expected that investigation of this region by

means of critical-frequency reflection should yield heights which change very little with increase in frequency until that frequency is reached which will penetrate the point of maximum ion-formation. Furthermore, it will be noticed that the point of maximum absorption increases in elevation with decreasing solar altitude. Hence one would expect the observed height of an ionized layer to increase with decreasing solar altitudes—and also, since the magnitude of the maximum decreases with decreasing solar altitude, that the observed density of ionization should decrease in the same way. This latter statement will only be true provided the time-lag between a change in the rate of ionization and a corresponding observable change in the magnitude of the ionization is sufficiently small. It is thus necessary to digress momentarily into a consideration of the time necessary to establish equilibrium in a gas subjected to an ionizing radiation.

The familiar equation which expresses the rate of change of ionization in a gas in which the particles disappear according to an n^2-law is

$$(\mathrm{d}n/\mathrm{d}t) = q - \alpha n^2 \tag{6}$$

This may be easily integrated if q is a constant independent of time. Although q is not independent of time, this will be a satisfactory approximation if the time to attain equilibrium is short. If $n=0$ when $t=0$ (an assumption giving the longest time) then the time taken to reach some arbitrary percentage of the equilibrium ion-content, for example 99 per cent, will be given by

$$t = 2.65/(\alpha q)^{1/2} \tag{7}$$

Anticipating the results of subsequent sections this may be determined for the region of the E-layer to be of the order of 20 seconds. Thus in this region the ionization may be expected to follow changes in the magnitude of the ionizing agent with great rapidity. It may be noted that this will mean a maximum density of the ionization almost simultaneously with maximum intensity of the ionizing agent a state of affairs which is not always necessarily the case.

Accordingly, accepting the initial hypotheses for the ionization, one may predict that the height of the E-layer will be least at noon, at which time there will be a maximum of ionization. The ionization-density and height of the layer should, furthermore, be symmetrical about noon in time. These predictions are compared with the available experimental data [3] in Table 1.

Table 1—*E-layer, latitude 40° north*

Quantity	Observed	Calculated
Ratio maximum ionization, December to June	0.54	0.42
Difference in minimum height, December to June	13.5 km	12 km
Ratio ionization at noon to that at 08:00 and 16:00 for June	0.67	0.73
Difference in height between noon and 08:00 and 16:00 for June	7.5 km	6 km
Ratio ionization at noon to that at 10:00 and 14:00 for December	0.88	0.82
Difference in height between noon and 10:00 and 14:00 for December	1.5 km	2 km

The agreement between the observed and calculated values is at least correct in trend and in order of magnitude.

Characteristics of ionization in the E-region

It is now of interest to see what may be said concerning the character of the ionization in an atmosphere of the type used in the above absorption-calculations. Fundamentally we must consider three possible processes of recombination after the initial ionization. These are: (1) Electron-positive-ion recombination; (2) electron-molecule (or atom) negative-ion formation; and (3) negative-positive-ion recombination. Before these processes may be considered in detail it is necessary to determine what rôle may be played by diffusion. The diffusion-process of ions and electrons will be determined in magnitude essentially by the speed of diffusion of the more massive components of the ionization, the positive ions. This must be so since, as has been pointed out elsewhere, no prolonged separation of charge can occur if the region be assumed field-free. Now the approximate distance which a molecule will diffuse on the average after a time t is given by $d = N^{1/2}\lambda$ where λ is the mean free-path of the particle and N is the number of collisions in time t. Using the above atmosphere, this distance may at once be calculated for different values of elevation above the surface of the Earth for times of the order of a half day. The results are given in Table 2. It will be

TABLE 2

Elevation	Distance diffused by an ion in 10^4 seconds
km	*km*
100	1/3
200	10
300	100

noticed that the diffusion-distance given by the above goes up as the inverse square root of the particle-density. Up to 200 km the extent of the diffusion-process is small enough to be neglected without further discussion. For greater elevations it seems that it may still not play an important daily rôle for the following reasons. At higher elevations the effect of the Earth's magnetic field becomes more important (the so-called long free-path region of Hulbert) and diffusion is retarded across the lines of force. Since these are approximately at 45° to the horizontal in middle latitudes, vertical diffusion will be reduced on this account. In addition the distribution which the ions would like to attain if no other fate awaited them would be an exponential one of the type $e^{-m'gz/kT}$. Inspection of the rate-of-absorption equation and Figure 1 shows that for high elevations the rate of absorption of radiation and hence, by assumption, the number of ions formed is closely proportional to the above exponential. Hence diffusion upwards will be slow because the particles are essentially in equilibrium at the time of their formation and diffusion downwards is into regions where the process goes much more slowly. For these reasons the effect of diffusion has been neglected in the treatment which follows. It may be noted that if the pressure be 10^{-5} atmos-

phere at 100 km the diffusion in this region will be less than a kilometer per day. Hence for this region at least the assumption would seem to be valid for almost any type of permissible atmosphere.

The three specific processes of destruction and formation of ions mentioned above have not been directly measured in the laboratory. However, enough is known about the character of such processes to enable estimates to be made with reasonable accuracy of their magnitude. Electron-positive-ion recombination has been measured by Kenty [4] for argon positive ions and 0.4-volt electron, obtaining a coefficient of recombination of 2×10^{-10}. Furthermore, it is highly probable theoretically that the coefficient is inversely proportional to the electron-velocity. If we assume electrons in thermal equilibrium with a gas at 250°, one obtains a value of 7×10^{-10} for the coefficient of positive-ion-electron recombination in argon at this temperature. If this be corrected for the difference in ionization-potentials of argon and oxygen, a value of 4×10^{-10} is obtained. In the absence of experimental work on positive ions of oxygen and electrons, this value will be assumed as holding also for this process. Such an assumption will not be greatly in error inasmuch as the process is one in which the excess energy is liberated in the form of radiation and such processes will not vary, at least by orders of magnitude, from one particle to another of similar ionization-potential.

Direct experimental work is also not available for the rate of formation of negative ions from oxygen atoms and electrons. Nevertheless the process must certainly occur, for monatomic negative oxygen ions have been observed in mass spectroscopy and the electron-affinity of the oxygen atom is known to be 2.2 volts [5]. Now the magnitude of the electron-capture cross-section with radiation of the liberated energy has been calculated for the hydrogen atom by Jen [6]. The hydrogen atom has an electron-affinity of 0.7 volt and the capture cross-section varies as the cube of the emitted frequency and inversely as the square of the electron-velocity. Accordingly a cross-section for electron-capture by an oxygen atom may be calculated of 1.5×10^{-19} cm². Since a capture-coefficient, β, may be obtained quite analogously to the recombination-coefficient α by multiplying by the electron-velocity, one finds β to be 1.6×10^{-12} for electrons and oxygen atoms. It may be noted that this cross-section is roughly a thousand times larger than in the similar process for molecular oxygen, values for which have been presented elsewhere [7]. Here again, the order of magnitude is probably correct as the process is not strongly dependent on the character of the attaching atom.

Finally one must consider the recombination-coefficient between positive and negative ions. Again experimental data are lacking but the magnitude of the process is known for molecular ions over a range of pressure, and a discussion of the problem over an extended pressure-range has been given by Loeb [8]. If the Thomson process applies in the E-region, then for pressures as given by the pressure-distribution resulting from the atomic oxygen hypotheses and for a temperature of 250° one obtains a value of the order of 2×10^{-9}, and it may be noted that for this process the coefficient of recombination varies at low pressures, directly as the pressure. The pure collision-process suggested by Loeb, has a value independent of pressure of about 10^{-10} or greater depending

upon the effective radius of collision. It is therefore probable that in the E-region the coefficient of ionic recombination has a value $\sim 10^{-9}$.

The equations for the gain and loss of ions in the E-layer may then be written

$$(\mathrm{d}n_-/\mathrm{d}t) = q - \alpha N_+ n_- - \beta n_- N_0 \tag{8}$$

$$(\mathrm{d}N_-/\mathrm{d}t) = q - \alpha N_+ n_- - \gamma N_+ N_- \tag{9}$$

$$(\mathrm{d}N_-/\mathrm{d}t) = \beta n_- N_0 - \gamma N_+ N_- \tag{10}$$

where q = number of ionizations/cc/sec, n_- = number of electrons/cc, N_- = number of negative ions/cc, N_+ = number of positive ions/cc, N_0 = number of neutral molecules/cc, α = coefficient of positive-ion-electron recombination, β = coefficient of electron-molecule negative-ion formation, and γ = coefficient of positive-negative-ion recombination. Theoretically it would be possible to solve these three equations simultaneously after inserting the proper values of the coefficients. This is, however, unnecessarily tedious on account of simplifications which may be introduced. In equation (8) we notice at once that when the value of N_0 is introduced, the third term has a value $\sim 10^6$ times that of the second term. Accordingly we will neglect the term in this equation which corresponds to the recombination of positive ions and electrons. This will be justified unless the result permits N_+ to grow to values comparable with N_0. The solution of this equation gives at once (if $n_- = 0$ when $t = 0$)

$$n_- = (q/\beta N_0)(1 - e^{-\beta N_0 t}) \tag{11}$$

This solution of equation (8) may then be substituted in equation (10). It will be noticed, however, that (8) attains its stationary value, $(q/\beta N_0)$, very quickly since $\beta N_0 \sim 10^2$. Hence if we are content with solutions after the first hundredth of a second, we may use the stationary value in (10) rather than the complete expression. Since $N_+ = n_- + N_-$, equations (9) and (10) assume the same form which for (10) is

$$(\mathrm{d}N_-/\mathrm{d}t) = q - \gamma N_-^2$$

of which the solution (assuming no or negligibly small ionization initially) is

$$-e^{2t\sqrt{\gamma q}} = (\gamma N_- + \sqrt{\gamma q})/(\gamma N_- \sqrt{\gamma q})$$

and the time to attain 99 per cent of the equilibrium-value $N_- = (q/\gamma)^{1/2}$ is $2.65/(\gamma q)^{1/2}$.

We must now consider the application of these equations to the E-layer. If the value of N_- observed experimentally be taken as 10^5 and the particle-density of the E-layer as $\sim 10^{14}$, then a value of $q = 1.6 \times 10^7$ ions/cc/sec is at once obtained. For the total absorption in the E-layer this corresponds to roughly 5×10^{13} quanta/sec cm^2. Since the number of quanta per cm^2 per second for a black body radiating at 6800°K with frequencies less than 1000 A, and having a total energy corresponding to that of the solar constant, is approximately 10^{10}, this would predict an intensity in the far ultra-violet portion of the solar spectrum 10^3 or more times as intense as that of pure black-body radia-

tion. Such a possibility has already been suggested by Saha [9] and McNish [10].

It is now necessary to see if three tacit assumptions which have been made above are justified. The first of these considers the time necessary to attain equilibrium in the E-layer as far as electrons and also negative ions are concerned. Calculation shows that electron-negative-ion equilibrium is attained in times shorter than 0.1 second, and the time to attain negative-ion-equilibrium turns out to be ~ 10 seconds. Secondly it must be justified that the number of electrons actually present is sufficiently great with respect to the equilibrium-number of negative ions to assure that the electrons are responsible for the reflection of an incident electromagnetic wave. Such a requirement is imposed by the magneto-ionic splitting of a returned wave. The equilibrium-value of N_- is given above as $(q/\gamma)^{1/2}$ which gives $N_- = 10^8$ or approximately 10^3 times as many negative ions as electrons. Since the oxygen atoms are 3×10^{-5} times as effective in electromagnetic reflection as the electrons, this is a very reasonable result. Finally, the number of positive ions is small enough to justify the neglect of the term $\alpha N_+ n_-$ in equation (8).

It will be noticed that the above hypotheses predict that the electron-density in the E-layer should fall off very rapidly immediately after sunset leaving the reflection largely to be carried on by the negative ions, and the density of these too will fall to low values before sunrise. No experimental evidence seems to be immediately available to check this point, particularly with regard to the character of the reflecting particle. In general, values of the E-layer ion-density are given only for the daytime hours. It should be pointed out, however, that it will be very difficult to reconcile a process whose time to reach equilibrium must be less than 10^3 seconds (since the E-layer maximum density occurs close to noon) and yet which can have a recombination-coefficient which permits ionization to last all night. If we abandon altogether the hypothesis of negative-ion formation and assume that the process involves only positive ions and electrons, then $(\alpha q)^{1/2} \simeq 10^{-3}$ and $(q/\alpha)^{1/2} \sim 10^5$. To reconcile these two equations requires $\alpha \simeq 10^{-8}$ which seems at least a factor of a hundred too large and which would furthermore cause the ionization to decrease to a tenth of its sunset value in a few hours. This point seems rather crucial and can only be settled by experiment. The only possible alternative would seem to be an explanation which involves negative-ion formation during the daytime and electron-recombination at night. This might occur if attachment were taking place to excited nitrogen molecules in the $^3\Sigma$ state. Such a process would have a capture cross-section ten to 100 times less than that for the formation of O^-. If the life of such an excited molecule is several seconds, a sufficient concentration might be built up to make this an important process, particularly if the dissociation of atomic oxygen at this level is not as great as suggested. The recombination of atomic oxygen after sunset would produce a similar effect, but since O_2 in the normal state possesses an electron-affinity, the result would be less pronounced than in the case of a participant N_2-molecule.

Characteristics of ionization in the F_1-region

It is generally stated that the F_1-region appears as a daytime shelf below the F_2-region. Examination of tables of height and critical frequency reveals that for this region the general behavior is very similar to that of the E-region. Both these phenomena suggest that a process similar to that producing the E-region occurs. Values of the atomic density with the law assumed above are of the order of 4×10^{11} which is sufficiently high to make the negative-ion process predominate since the third term in equation (8) is still 10^3 times larger than the electron-recombination term. The same argument may then be carried through as in the case of the E-layer which then leads to a time of about one second to attain electron-negative-ion equilibrium; a value of $q=5\times10^5$ ions cc sec if $n_-=3\times10^5$; and $N_-=2\times10^7$ ions/cc. The time to attain positive-negative-ion equilibrium will be ~ 100 seconds. It will further be noticed that the diurnal variation in height will be approximately twice as great at this elevation as at 100 km, and it is seen in Table 3 that such

TABLE 3—*F_1-region, latitude 40° north*

Quantity	Observed	Calculated
Ratio maximum ionization, December to June	0.73	0.42
Difference in minimum height, December to June	15 km	22 km
Ratio ionization at noon to that at 08:00 and 16:00 for June	0.77	0.73
Difference in height between noon and 08:00 and 16:00 for June	19 km	12 km
Difference in height between noon and 10:00 and 14:00 for December	6 km	4 km
Ratio ionization at noon and at 10:00 and 14:00 for December	0.98 (?)	0.82

variations are indeed greater for the F_1-region than for the E-region. The diurnal and seasonal range in ionization should also be roughly the same as for the E-region which is also seen to be effectively true. The ionization in this region should die off fairly rapidly at night as indeed seems to be the case.

Characteristics of ionization in the F_2-region

Inspection of equation (8) shows that for regions above 200 km, the importance of the electron-positive-ion recombination term rapidly grows with respect to the negative-ion-formation term. Accordingly in this region it is suggested that during the daylight hours, electron-positive-ion recombination plays an important part. Furthermore, inspection of Figure 1 shows that during a large portion of the day, the rate of ionization in this region will be sensibly constant. One can therefore solve equation (8) which will be of the form

$$(\mathrm{d}n_-/\mathrm{d}t)=q-\alpha N_+n_-$$

obtaining the result

$$n_-/n_\infty=(Ae^{2t\sqrt{\alpha q}}+1)/(Ae^{2t\sqrt{\alpha q}}-1)$$

in which $A=(n_0+n_\infty)/(n_0-n_\infty)$, $n_\infty=\sqrt{q/\alpha}$, and n_0 is the value of the ion-density when $t=0$. The time to attain equilibrium will of course

depend upon the value of the initial ionization, being shorter when this is large. The order of magnitude will be given in any case by $2.65/(\alpha q)^{1/2}$ and the equilibrium-value of ionization by $(q/\alpha)^{1/2}$. If the equilibrium-value of ionization is actually reached diurnally in the F_2-layer (and this appears to be approximately the case), one obtains a value of $q=(4\times10^{-10})(10^6)^2=400$ ions/cc/sec. We notice that the value of the ionization per cubic centimeter at 300 km due to the band of radiation which produces the E-layer is 10^{-5}, its value at its maximum, or of the order of 100 ions/cc/sec. It is thus tempting to suggest that the F_2-region does not result from the absorption of a special band of solar radiation, but owes its origin to the fact that as negative-ion formation gets less and less, a smaller amount of absorption of ionizing radiation will produce a much greater number of electrons. The ionization in this region due to that radiation which produces the F_1-layer will also be about 3×10^{-3} times less, or of the order of 1000 ions/cc/sec. Both of these values are in rough agreement with the value required to maintain the ionization in the F_2-region.

We notice on these premises that the time required to reach equilibrium becomes of the order of 10^4 seconds or several hours depending on the exact values of q and α. In any event it need not surprise us if the maximum ionization in the F_2-region did not occur at local noon—in fact the maximum may be shifted into the afternoon. Further, once having reached its maximum it should stay constant until shortly before sunset due to the constancy of q at high elevations. Thus the behavior will be radically different from either of the two lower layers.

After sunset recombination in the upper regions of the F_2-layer will take place according to the equation

$$(\mathrm{d}n_-/\mathrm{d}t)=-\alpha n^2_-$$

which has the familiar solution

$$\alpha t=(1/n_- -1/n_0)$$

In the regions adjacent to that of the F_1-layer, loss of electrons after nightfall will take place primarily by attachment to oxygen atoms, giving rise to an exponential law of decay. As we have seen for the F_1-layer, this latter process is more rapid than electron-recombination, and hence there will appear to be a loss of electrons in the F_2-region which will be more rapid in the lower levels and cause the effective height of the region to *increase* after nightfall as well as to decrease in electron-density by recombination and ion-formation.

Thus it would be predicted on this theory that shortly before ground sunrise ionization should begin to be built up in the region occupied by the F_1-level and above. At some distance above the F_1-region the ionization increases (though the rate of ionization decreases) owing to the decreased rate of negative-ion formation. If no change in density took place in the atmosphere during the day, the F_2-level should stay substantially constant. After the removal of the ionizing agent at sunset the lower portions of the F_2-level should rapidly disappear giving rise to an apparently increasing layer-height until electron-recombination predominates. At this time the height will remain constant until the next sunrise, which will again produce ionization at lower levels and the

process will repeat itself. For purposes of illustration a theoretical plot of the density of ionization in the F_2-layer as a function of time of day has been given in Figure 2. This assumed a maximum ion-desity of 10^6 electrons per cc and a recombination-coefficient of 4×10^{-10}.

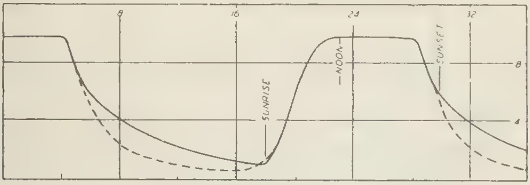

FIG. 2—HYPOTHETICAL ION-DENSITY IN F_2-REGION
[DOTTED LINE CORRESPONDS TO A (1/t)-DECAY AFTER SUNSET AND FULL LINE TO AN EXPONENTIAL DECAY]

The rate of ionization was assumed constant except for an hour following sunrise and preceding sunset when it was reduced to one half its value at noon. Two types of decay have been plotted according to whether an exponential decay or a $(1/t)$-decay is followed after nightfall. Much of the general behavior indicated by this curve is exhibited by the F_2-region in a qualitative fashion. The ion-densities decrease rapidly after sunset until shortly before sunrise. Whether this is according to an exponential or a $(1/t)$-law is difficult to say from the existing data, since the form of the decay approximates either. At sunrise, or shortly before, the ion-density begins to increase again and generally increases throughout the day, although there are irregularities in the process which sometimes result in small midday minima or similar phenomena. It would seem, however, on the whole, that a smaller value of the recombination-coefficient than employed for Figure 2 would give a behavior more nearly like that observed. Since Haurwitz has suggested temperature of the order of 1000° for high levels in the atmosphere, these very properly suggest a lower value for α than employed here, inasmuch as $\alpha \propto (T)^{-1/2}$. The height of the F_2-region increases after nightfall in accordance with the above suggestion reaching a fairly constant height about midnight. The height then decreases when ionization starts in shortly before ground sunrise. The behavior during the day, however, is anomalous as the height again increases after sunrise, reaches a maximum at noon and then decreases. The value of the maximum height at noon is strongly seasonally dependent and may be greater or less than the midnight height. Accordingly it seems necessary to adopt the suggestion which has been made elsewhere [11] that the upper atmosphere undergoes a heating and expansion during the day, thus causing the effective rise of the F_2-level. The seasonal dependence of this phenomena, being much less in winter than in summer, seems to substantiate this suggestion. This may decrease the density in the heated region relative to surrounding ones and cause a decrease in the observed ion-density, thus accounting for the depression at noon in ion-density and the appearance of double maxima. This phenomenon as well is less in winter than in summer.

Certain other phenomena seem to appear in the published data concerning the F_2-region which are tempting to consider. Some of these will be considered here in the light of the above hypothesis.

Time and magnitude of maximum

The time of maximum ion-density in the Northern Hemisphere shifts from late afternoon in summer to nearer noon in winter. This suggests a seasonal change in either q or α or both. The magnitude of the maximum ion-density is greater in winter than summer by a factor of about 1.35. Since q depends on the atmospheric density at a given level and may then vary as $(1/T)$ and α varies as $T^{-1/2}$, then the time to attain maximum should vary as $T^{3/4}$ and the magnitude of the maximum as $T^{-1/4}$. Both of these facts suggest temperatures in summer higher than in winter by a factor of about 1.5.

This suggestion, however, meets a fundamental difficulty for, as pointed out by Berkner, Wells, and Seaton [12], the maximum seasonal ion-density of the F_2-region is reached simultaneously in both hemispheres. It seems therefore inadvisable to place too much reliance upon calculations of this type until further data have determined the cause of the failure of the two hemispheres to respond similarly.

Fluctuations in F_2-region

The fluctuations in ion-density during the day in the F_2-region caused by possible variations in intensity in the ionizing portion of the solar spectrum are interesting to consider. In general such changes will take place more slowly but will last longer in the F_2-region than in either of the other two regions. For the sake of argument one may consider a change in the solar radiation such that q is increased by a factor of 100 over its normal value and that this abnormal intensity lasts for 100 seconds. At the end of this time the electron-density will be 1.8 times its normal value in the F_2-region, and nearly 100 times greater in both the F_1- and the E-regions. However, within a few seconds after the decrease of intensity, the ionization in the E- and F_1-regions will return to normal, but the ionization in the F_2-region will still be 50 per cent greater than normal after 10^3 seconds. Thus rapid fluctuations which might escape notice in the lower layers have effects detectable over much greater time-intervals in the F_2-regions. Superimposed on fluctuations of this type must be others of a mechanical nature, corresponding to processes similar to those which cause the daytime rise in level of the F_2-regions. These of course cannot be treated here, but must be the cause of such anomalies as the reported occasional increase of ion-densities in the F-region after midnight.

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HEIGHTS OF ELECTRIC CURRENTS NEAR THE AURORAL ZONE

By A. G. McNish

Intense magnetic disturbances lasting for an hour or more are frequently observed in the vicinity of the auroral zone. Birkeland[1] has named these disturbances "polar elmentary storms" and ascribed them to electric currents produced by the streaming of electrified solar corpuscles through the Earth's magnetic field. The writer[2] has suggested that they are due to electric currents resulting from dynamo-action in the auroral zone, the atmosphere being heated there by impact of solar corpuscles. This was an extension of the theory proposed by Chapman[3] to account for the world-wide characteristics of magnetic storms.

In order to test these hypotheses the configuration and heights of the assumed currents must be known. Dynamo-action is an improbable cause if the currents flow at very great heights where the direct-current conductivity is slight because the gyromagnetic frequency of ions or electrons is great in comparison with their collisional frequency. If the currents flow at low heights where mean free-paths are short it is unlikely that they are actual streams of electrified particles impelled by kinetic energy they had in outer space. The exact limiting regions for these two effects cannot be assigned from data available at present, but roughly it may be said that dynamo-action cannot extend much above 150 km while corpuscular streams should have their lower limit at 200 to 300 km.

Distribution of the field-changes in the region of the auroral zone is relatively simple. For the larger disturbances, particularly those occurring near midnight, the horizontal component of the perturbation-vector is directed southward, having its maximum value near the auroral zone. The vertical component of the perturbation-vector is directed upward south of the auroral zone and downward north of the auroral zone. Its magnitude is zero where the horizontal component has its maximum and is greatest about 200 km north and south of the auroral zone. At great distances from the auroral zone the effect of the perturbation is comparatively slight. The effect of the disturbance extends for a much greater distance along the auroral zone than perpendicular to it, the above-described distribution of the perturbation-vector applying roughly along any line perpendicular to the auroral zone within several hundred kilometers of the region where the effect of the perturbation is greatest. Thus, the field-changes are very similar to those which would result from a current flowing in a long wire suspended parallel to the auroral zone and several hundred kilometers above it.

Birkeland was among the first to investigate the heights of these currents. He assumed that the current was confined to a very narrow region, as if flowing along a wire. Selecting occasions when the apparent direction of the current is perpendicular to a line connecting two observing stations, the location and intensity of the hypothetical current is com-

[1]The Norwegian aurora polaris expedition 1902-1903, Christiania (1913).

[2]Trans. Edinburgh Meeting, 1936; Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 10, 282-289 (1937).

[3]Proc. R. Soc., 95, 61-83 (1918).

pletely determined by the field-changes at those two stations. The intersection of perpendiculars to the perturbation-vectors at the two stations defines the location of the current. The intensity of the current is determined by the magnitude of the perturbation-vector at either station, the perturbation-vector at the other station serving as a check on the intensity.

No correction was made in Birkeland's calculations for the effects of currents induced in the Earth. Chapman[4] has pointed out that neglect of the induced currents results in an overestimate of the heights and intensities of the currents. However, a definite estimate of the ratio of the induced field to the primary field has never been made for the disturbances in the region of the auroral zone. One might assume that 0.6 of the horizontal field-changes arise from currents above the Earth's surface since this ratio has been established for the diurnal variations by spherical harmonic analysis. Chapman computed the world-wide current-system for magnetic storms on the basis of this assumption. Other considerations suggest that this hypothesis will not hold for the very narrow currents flowing near the auroral zones.

To explain the relation between the primary and induced fields of the solar and lunar diurnal variations and the storm-time variations during magnetic disturbances it has been necessary to assume that the outer portion of the Earth is essentially non-conducting down to a depth of over 200 km, below which level the conductivity increases greatly. Assuming the core to be perfectly conducting the induced field at the Earth's surface is the field of the electrical image of the external line-current located as far below the surface of the conducting core as the primary current is above it. Thus, if the line-current is 200 km above the Earth's surface the image giving rise to the induced field would be 600 km below the Earth's surface and the field arising from the external current would be three-fourths of the field observed immediately under the line-current. If the current is at a height of 100 km the portion of the field due to the external current is still greater. Furthermore, this ratio is not maintained for all points on the Earth's surface and the assumptions stated above regarding the depth and conductivity of the core make the ratio of the induced to the inducing fields greater than they probably are. The assumption that the line-current and its image extend to infinity and consequently, that their magnetic effects are inversely proportional to the distance from either decreases in validity owing to the great depth of the current-image. A diagrammatic expression of these ideas is presented in Figure 1. Over portions of the Earth covered by deep oceans the inductive effects are likely to be much greater.

The geometrical solution of the problem as employed by Birkeland and subsequently by others is not adequate because of ignorance regarding the induced field. If the external current is distributed in a broad sheet the assumption of a line-current does not hold and the heights and intensities given for the current are in error, as Birkeland has pointed out. Unfortunately the spatial variations of the disturbance-field in the neighborhood of the auroral zones are so great that they are not readily representable by spherical harmonics. However, a few simplifying assumptions permit the application of another analytical

[4]Terr. Mag., **40**, 349-370 (1935).

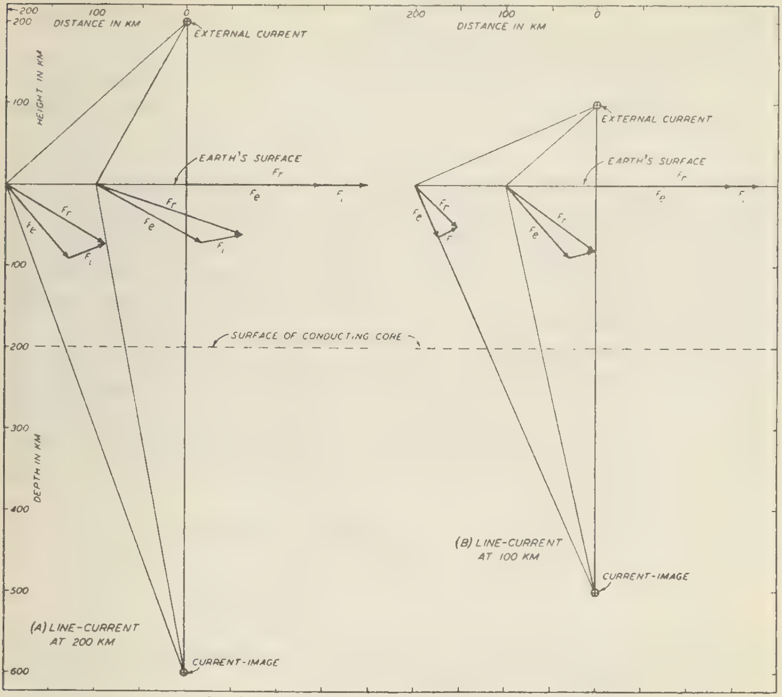

FIG. 1—MAGNETIC FIELDS (F_e, F_i) DUE TO LINE-CURRENT AND TO CURRENT-IMAGE INDUCED IN CONDUCTING CORE

method which, except for an unimportant constant term, leads to a unique separation of the internal and external fields and inferences regarding the heights and configurations of the currents giving rise to the fields.

It is assumed that (1) the disturbance-field extends uniformly to great distances east and west of a vertical plane which is perpendicular to the auroral zone in most cases, (2) the extent of the field in this plane is very much less than its extent perpendicular to the plane, and (3) the curvature of the Earth may be neglected. In accordance with these assumptions the disturbance-field may be treated as a problem in two-dimensional potential-theory.

If the disturbance-field arises from electric currents flowing above and beneath the Earth's surface then at all points in this plane above the Earth's surface but beneath the lowest height of the external currents it is derivable from a potential

$$W = F_e(x, z) + F_i(x, z)$$

The subscripts refer to the contributions of the external and internal currents, respectively, and the coordinates x and y are measured in this plane positively southward and upward, respectively. The potential

within the range $x=0$ and $x=2\pi$ may be expressed with respect to its value at $x=0$ by a linear term and a series of the form

$$W=A_0x+\sum_1^n\left[e^{\alpha nz}\left(A_{e,n}\cos nx+B_{e,n}\sin nx\right)+e^{\beta nz}\left(A_{i,n}\cos nx+B_{i,n}\sin nx\right)\right]$$

subject to the condition that the periodic terms in the potential due to currents within the Earth vanish at $z=+\infty$ and those due to currents above the Earth's surface vanish at $z=-\infty$. These conditions are satisfied if $\alpha=+1$ and $\beta=-1$. The term A_0x may be due to external currents, internal currents, or both; its significance will be obvious later.

The horizontal and vertical magnetic fields, X and Z, are the derivatives of W with respect to x and y.

$$X=-\partial W/\partial x=-A_0+\sum_1^n\Big[ne^{nz}\left(A_{e,n}\sin nx-B_{e,n}\cos nx\right)$$
$$+ne^{-nz}\left(A_{i,n}\sin nx-B_{i,n}\cos nx\right)\Big]$$

$$Z=-\partial W/\partial z=\sum_1^n\Big[ne^{nz}\left(-A_{e,n}\cos nx-B_{e,n}\sin nx\right)$$
$$+ne^{-nz}\left(A_{i,n}\cos nx+B_{i,n}\sin nx\right)\Big]$$

Since $z=0$ at the Earth's surface the exponential factors reduce to unity and the components of the field are given by

$$X=-A_0+\sum_1^n\left[n\left(A_{e,n}+A_{i,n}\right)\sin nx-\left(B_{e,n}+B_{i,n}\right)\cos nx\right]$$
$$Z=\sum_1^n\left[n\left(-A_{e,n}+A_{i,n}\right)\cos nx+\left(-B_{e,n}+B_{i,n}\right)\sin nx\right]$$

Observed values of X and Z at the Earth's surface may be expressed in series of the form

$$X=\sum_0^n\left(a_{n,x}\cos nx+b_{n,x}\sin nx\right)$$

$$Z=\sum_1^n\left(a_{n,z}\cos nx+b_{n,z}\sin nx\right)$$

The coefficients $a_{n,x}$, $b_{n,x}$, $a_{n,z}$, and $b_{n,z}$ are immediately identified with $n(-B_{e,n}-B_{i,n})$, $n(A_{e,n}+A_{i,n})$, $n(-A_{e,n}+A_{i,n})$, and $n(-B_{e,n}+B_{i,n})$, respectively, a_{0x} being identified with $-A_0$. Thus each individual coefficient in the contributions of the internal and external currents may be obtained by solution of the pair of simultaneous equations in which it appears. No separation is possible for the term $-A_0$.

As the series representing the field-change applies throughout the region between the Earth's surface and the lowest height of the current, the horizontal component of the field-change due to currents above the Earth's surface may be computed for any height within this region. Such a computation is identical, except for a factor of proportionality, with the density of current in a thin sheet at the same height which would give rise to the observed field-change. Therefore the current in a thin sheet necessary to produce the field-change is known for any assumed height. Although a basic principle of potential-theory prohibits unique determination of both height and distribution of current, certain heights and configurations may be dismissed from consideration as improbable while other assumed configurations may be eliminated as impossible.

For illustration a disturbance prominent in the records from northern Europe lasting from $20^h 30^m$ to $23^h 15^m$ GMT on January 15, 1933, has been analyzed by this method. The field-changes in the various magnetic elements at all stations were taken as the departures at $21^h 45^m$ as referred to the means of those elements for $20^h 30^m$ and $23^h 15^m$. Horizontal components of the field-change are represented in Figure 2 by "current-arrows" drawn perpendicular to and proportional to the

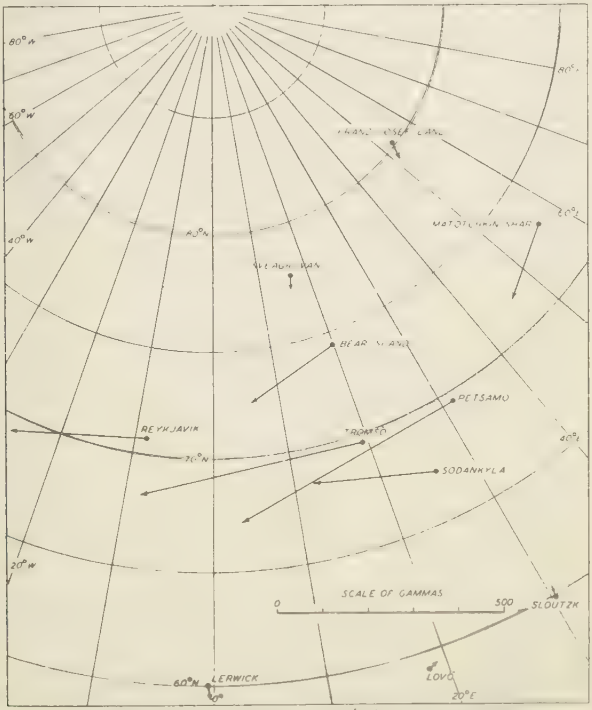

FIG. 2—CURRENT-ARROWS FOR DISTURBANCE AT $21^h 45^m$ GMT, JANUARY 15, 1933

horizontal magnetic vectors at all stations. The arrows suggest the field-change is due principally to a concentrated flow of electric current from east and west, the extent of which in the direction of flow is much greater than its extent perpendicular to the direction of flow. If this current is within 300 km of the Earth's surface the assumptions upon which the method of analysis is based are adequately approximated. The most intense current indicated by the arrows is near the meridian 20° east close to which there are seven magnetic observatories—Sveagruvan, Bear Island, Tromsö, Petsamo, Sodankylä, Lovö, and Sloutsk. The central plane for the disturbance was taken to contain the meridian 20° east and the departures observed at the seven above-mentioned observatories were taken as representative of the distribution of disturbance in that plane. Results of observations at the remaining observatories shown in Figure 2 were not used directly in the analysis as they lay too far from the central plane.

Distribution of the vertical and horizontal components of the field-change in the central plane is shown in Figure 3. An approximate curve (dashed) was drawn through the points extending over a range of 48°,

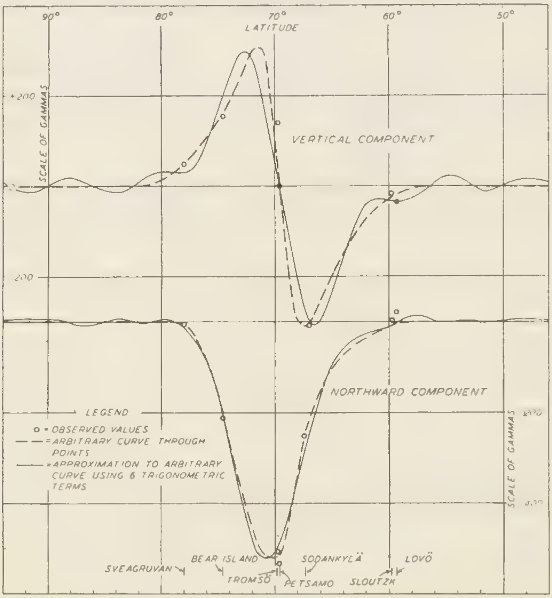

FIG. 3—PERTURBING FORCE DURING BAY AT 21^{h}45^m GMT, JANUARY 15, 1933

which corresponds to the range $x=0$ to $x=2\pi$. At considerable distances from the center of disturbance both components of the field have been assumed to vanish. This arbitrary procedure is equivalent to assuming that the return-flow occurs at infinity and makes no contribution to the magnetic field near the auroral zone. This is contrary to actual conditions, for much if not all of the current flowing along the auroral zone

maintains its continuity by a return-flow in the Earth's atmosphere and contributes, though perhaps only slightly, to the magnetic field at the auroral zone.

Twenty-four regularly spaced points were scaled from each of the approximate curves and fitted by a six-harmonic trigonometric series. The coefficients of this series and the corresponding coefficients of the series representing the internal and external coefficients of the field-change are shown in Table 1. The portion of the field of internal origin is relatively small. The constant term $-A_0$ which appears in the series for the horizontal force has the value $+79$ gammas. This was arbitrarily apportioned between the external and internal contributions in the ratio 60 to 19 as such apportionment roughly minimizes the negative portions of the curves representing the external and internal contributions to the horizontal component. In the discussion which follows no conclusions are sensibly affected by this apportionment.

The current-density in a thin sheet which would give rise to the ex-

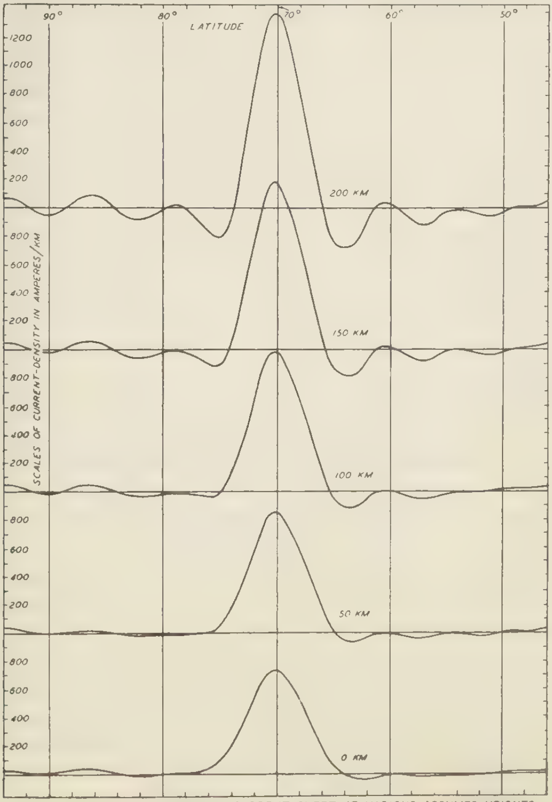

FIG. 4—EQUIVALENT WESTWARD CURRENT-SHEET AT VARIOUS ASSUMED HEIGHTS CAUSING BAY AT $21^h 45^m$ GMT, JANUARY 15, 1933

Table 1—*Coefficients of harmonics of magnetic disturbance near auroral zone at* $21^h\,45^m$ *GMT, January 15, 1938*

Degree n	Coefficient							
	$n(A_{e,n}+A_{i,n})$	$n(-A_{e,n}+A_{i,n})$	$n(-B_{e,n}-B_{i,n})$	$n(-B_{e,n}+B_{i,n})$	$nA_{e,n}$	$nA_{i,n}$	$nB_{e,n}$	$nB_{i,n}$
	γ	γ	γ	γ	γ	γ	γ	γ
1	−15	+2	+147	+59	− 8	− 7	+103	+44
2	+25	0	−114	−89	+12	+13	−102	−12
3	−30	−1	+ 80	+85	−15	−15	+ 82	− 2
4	+30	+1	− 39	−64	+15	+15	− 52	+13
5	−23	−1	+ 17	+46	−11	−12	+ 32	−15
6	+13	+2	− 9	−35	+ 6	+ 7	− 22	+13

ternal portion of the field-change for various assumed heights is shown in Figure 4. At a height of 200 km the distribution closely resembles the six-harmonic trigonometric representatives of a line-current as shown in Figure 5. From this it is concluded that if the particular disturbance in

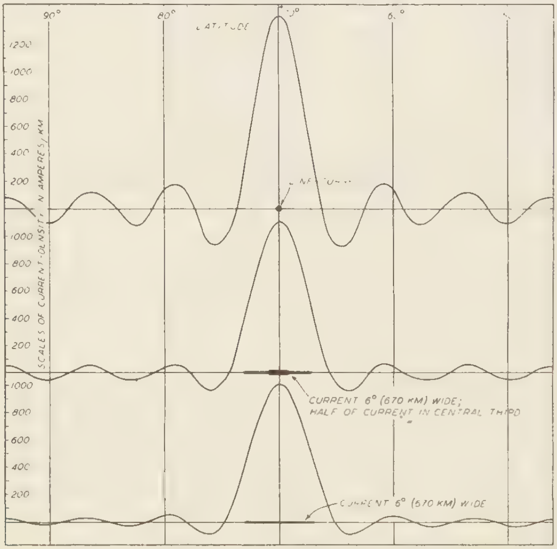

FIG. 5—HYPOTHETICAL CURRENT-SHEETS AND 6-HARMONIC APPROXIMATIONS TO THEM

question was produced by a line-current it was located at a height not greater than 200 km. Assumption that the current-sheet was at a greater height would require strong side-bands in the distribution, that is, as if the sheet consisted of several strips with currents flowing in opposite directions in adjacent sections. Figure 5 also reveals that the current-distribution at a height of 100 km is closely approximated by a uniformly dense flow along a strip extending over six degrees of latitude or roughly 670 km.

A better basis for discriminating among these various possibilities is afforded by Figure 6 in which is plotted the ratios of the various harmonics to the first for several assumed heights of the actual current-distribution and for two hypothetical distributions. The nature of the current-distribution is indicated by the relative intensities of the various harmonics. Clearly, the hypothesis of a broad current at 100 km or less seems to fit the facts better than the hypothesis of a line-current at 200 km, although the results are not sufficiently definite to arrive at final conclusions on this point.

No similar treatment was given the current of internal origin the distribution of which is shown in Figure 7, assuming the whole current

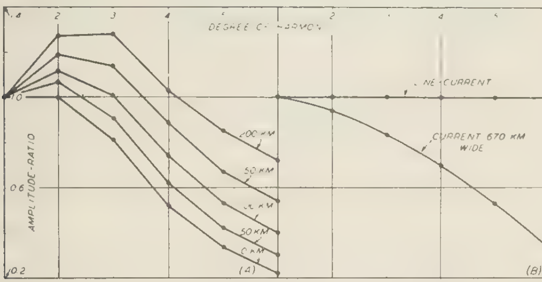

FIG. 6—AMPLITUDE-RATIO OF HIGHER HARMONICS TO FIRST HARMONIC: (A) EQUIVALENT CURRENT DISTRIBUTION AT VARIOUS HEIGHTS TO PRODUCE OBSERVED EFFECTS; (B) HYPOTHETICAL DISTRIBUTIONS

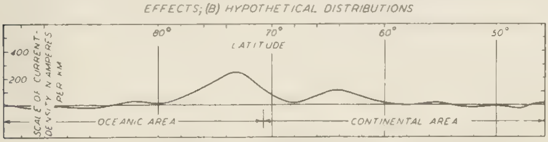

FIG. 7—CURRENT-DISTRIBUTION AT EARTH'S SURFACE GIVING RISE TO INTERNAL PORTION OF DISTURBANCE AT $21^h 45^m$ GMT, JANUARY 15, 1933

to be flowing in the surface of the Earth. It may be of no significance although it is interesting to note that the greatest density of flow occurs where the central plane intersects the sea-coast.

In presenting this paper it is the writer's purpose to describe the method and illustrate its application. No generalization should be attempted from examination of a single case. Further examination of other manifestations is in progress with the view of including cases where the disturbance takes place almost wholly over oceanic areas. In conclusion the writer wishes to acknowledge his indebtedness to Dr D. la Cour through whose good offices the valuable records from the Second International Polar Year have been made available for study at the Department of Terrestrial Magnetism.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C., February 15, 1938

NOTES

(See also page 96)

1. *Non-magnetic vessel of the Arctic Institute*—We are glad to note from the first issue of "Problems of the Arctic" that the Ship-Building Research Bureau of the Arctic Institute has completed the preliminary plans of a non-magnetic ship, destined to carry out magnetic work in the Arctic Ocean. The need of eliminating the effects of magnetic materials on the instruments and of securing sufficient stability for navigation through the ice has presented serious problems in working out the plans. For determining the chief elements of the ship, the construction of the hull, the type of engine and auxiliary machinery (which will be of non-ferrous metals), a study was made of the *Fram*, *Maud*, and whaling vessels. The type chosen is that of a three-masted motor-sailing schooner with 300 horse-power engine. The problem of increasing the navigation-range of the vessel has been satisfactorily solved by use of a considerable area of sail. The magnetic instruments are to be housed in two deck-houses on the upper deck. The living quarters are planned for a crew of twenty men—deck-hands 12, engine-room staff 3, scientific staff 5.

2. *Giant pulsations in Iceland*—Referring to the note (Terr. Mag., **42**, 429, 1937), regarding the establishment near Reykjavik of two stations for quick-run magnetic registration in connection with the investigation of giant pulsations, we learn that no giant pulsation was recorded during the season of 1937. In view of the importance of obtaining information regarding this phenomenon, it has been decided to continue this work for another summer, and it is gratifying to learn that the Postmaster General of Denmark has agreed to collaborate with the Danish Meteorological Institute in the maintenance of these two stations in Iceland for that purpose.

3. *Magnetic storms of January, 1938*—Very severe magnetic storms occurred on January 16, 22, and 25. The storm on the 25th gave ranges in the magnetic elements at Cheltenham, Maryland, which have not been exceeded since the great storm of July, 1928; the ranges were approximately 2° 46′ in D, greater than 880 gammas in H (maximum beyond limit of record), and 780 gammas in Z. At the Niemegk Observatory in Germany, during the storm of January 25, there was a great auroral display and the ranges in the magnetic elements were approximately 800 gammas in X, 500 gammas in Y, and 500 gammas in Z; at the Huancayo Magnetic Observatory in Peru the recorded ranges were 22′ in D, 1100 gammas in H, and 125 gammas in Z, while at Watheroo Magnetic Observatory in Western Australia they were 39′ in D, 396 gammas in H, and 249 gammas in Z.

The radio operator of the MacGregor Arctic Expedition at Reindeer Point, Greenland, reports that during the period January 14 to 24, 1938, there were several days when no radio signals were received, owing to the very severe magnetic disturbances prevailing at that time.

4. *Magnetic work in Arabia and Irak*—J. T. Murrell and Otto Wendenburg of the Gulf Research and Development Corporation of Pittsburgh, Pa., during May 8 to 26, 1937, occupied six stations in Arabia and Irak, namely Madaniyat, Bahra, Gahlula, Kuwait (Koweit), in Kuwait and Province, Arabia, Basra and Bagdad, in Irak. Of these stations Kuwait, Basra, and Bagdad had been previously occupied by observers of the Carnegie Istitution of Washington, so that the data thus obtained will serve for studies of the secular change in this region. A remarkable feature of the work of Murrell and Wendenburg lies in the fact that the instructions for making the observations, made with magnetic instruments loaned by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, were transmitted to them in the field by correspondence as they had had no previous training in this particular type of field-work.

5. *Ionospheric observations at Huancayo Magnetic Observatory*—The auto-multi-frequency ionospheric recorder was put into continuous operation at the Huancayo Magnetic Observatory on November 17, 1937, operating over a frequency-range of 3.28 to 16.0 megacycles per second. On December 8, 1937, this range was extended to 0.516 to 16.0 megacycles per second. Continuous operation over the latter range will be continued indefinitely yielding four complete records of ion-distribution through the outer atmosphere per hour. The early date at which these observations were commenced was made possible by the efforts of the staff at the Huancayo Magnetic Observatory consisting of F. T. Davies, H. W. Wells, H. E. Stanton, and W. W. Culmsee.

6. *Society of Exploration Geophysicists*—The fall meeting of the Society of Exploration Geophysicists was held at the Rice Hotel, Houston, Texas, November 19 and 20, 1937.

ON THEORIES OF MAGNETIC STORMS AND AURORAE

By S. Chapman

(1) In *Reviews of Modern Physics*, January 1937, E. O. Hulburt gives an interesting account of theories of magnetic storms and aurorae (among other subjects). The incompleteness and inadequacy of the existing corpuscular theories of these phenomena are described (pp. 61, 62) in terms to which, as an advocate of such theories, I take no objection; the difficulties of putting corpuscular theories into quantitative form have as yet precluded them from any right to claim much confidence or success. I should welcome sound criticism of the corpuscular theory proposed by Ferraro and myself, and further attempts to develop it.

(2) The review also describes the ultra-violet light theory, due to Hulburt [see 1 of "References" at end of article] and Maris [2]. As is natural in so difficult a subject, this theory has been gradually modified, partly in response to criticisms urged by me [3, 4] against its first [1] and second presentations [2].

(3) An argument to which I attached much importance, in my second criticism [4], was that of flying ions that descend in the auroral zone and there produce aurorae will have a velocity, according to the ultra-violet light hypothesis, of only about 10 km per sec. It then seemed, and still seems to me, impossible that such slow particles can account for the sudden appearances and motions of auroral luminosity in rayed draperies and other mobile forms of aurorae, at levels down to and below 100 km. It is true that we cannot say with certainty that these well-known phenomena are due to the sudden penetration of corpuscles to these levels, from outside the atmosphere; but this seems most likely, and is generally accepted. This view is supported also by Störmer's remarkable photographs of partly sunlit auroral rays [5], which extend into the shadowed region of the atmosphere, and sometimes show a middle portion of reduced intensity; it is most natural to regard such rays as due to the passage of beams of corpuscles with diminishing speed through layers of air of varying density. The ultra-violet light theory, on the other hand, regards the corpuscles as descending freely along the lines of magnetic force, "by temperature-diffusion and electro-magnetic drift," with a velocity of the order of 1 meter per sec. This conception gives no inkling of how the rapid auroral changes are produced.

(4) Because the third presentation [6] of the ultra-violet light theory did not meet this criticism, and for other reasons, I have not hitherto commented on the theory in its present form; but since the theory is still described [7] as "adequate to explain the complicated storm-variations of the terrestrial-magnetic field, the auroral zone, the spreading of the aurora into low latitudes during strong storms, the delay of appearance of aurorae after incipience of the storm, and other observed facts" (*l. c.* p. 68) it seems desirable to point out other unsatisfactory features, in order that the theory may if possible be further modified to remove them.

(5) Before doing so, however, it may be recalled that A. G. McNish [8] recently pointed out that the intense ultra-violet solar flares observed in the Western Hemisphere during 1936, which were accompanied by notable radio fade-outs, did not produce magnetic storms, and that this fact is adverse to the ultra-violet light theory of magnetic storms.

(6) While this argument is cogent, it is not necessarily conclusive, as was pointed out in the paper, because the light from the solar flares referred to was much more penetrating than that proposed by Hulburt and Maris as the cause of magnetic storms; the solar flares ionized the atmosphere mainly in a layer below 100 km height, whereas Hulburt and Maris postulated light of weak penetrating power, whose main action on the atmosphere was exerted at much higher levels.

The new criticisms here offered are based on discrepancies between two primary *observed* features of magnetic storms, and the corresponding features to be inferred from the ultra-violet light theory. The third form of the theory gave modified explanations of both these principal features of a storm, namely, the main phase (during which the horizontal magnetic force or *HF* is reduced), and the intense disturbance-field near the auroral zone.

(7) The main phase was explained as due to the heating of the atmosphere by the solar flare: The air expands, and this vertical motion, by dynamo-action, induces a westward current flowing round the Earth. This hypothesis is open to the criticism that the atmospheric heating, and resulting dynamo-action, must be confined almost wholly to the day-hemisphere of the Earth, so that the westward induced current, and its associated decrease of *HF* at the Earth's surface, would be far greater on the noon than on the midnight meridian (and, generally, greater on the sunlit than on the dark hemisphere). Actually the *HF* decrease is approximately equal on these two meridians, and its inequality in longitude is between the *post* and *ante meridiem* hemispheres, the intensity being greater over the former.

Such a heating and dynamo-action as is proposed must affect a thicker layer of the outermost atmosphere than that from which most of the neutral particles are ejected (according to the theory) to high levels whence, after ionization, they follow the lines of magnetic force towards the polar region. The main phase of the storm attains its maximum, for intense storms, after eight hours from the commencement [9]; during this period the part of the atmosphere that had just passed into the Earth's shadow at the beginning of the storm would have received no heating or excess ionization from the supposed solar flare; it seems most unlikely that there could be as strong an abnormal westward current in that region as over the sunlit hemisphere.

(8) The great and systematic distribution of magnetic disturbance in and near the auroral zones was also explained in a new way in the third form of the theory; a diamagnetic hypothesis gave place to a magnetic-gravitational drift-current hypothesis. As McNish [10] has pointed out in another connection, both these types of hypothesis are rather "rigid," since they predict the *sign* of the magnetic effects quite definitely, and the intensity depends practically only on one variable, namely the number-density of the freely-spiralling electric charges in the region considered. Thus it is stated [7] that the electric drift-current along the auroral zone, caused by the motion of charges that have descended into

the zone from high above the middle belt of the Earth, is eastward, with maximum intensity at 17^h or 18^h. A diagram was drawn [6] showing the return currents as flowing partly within the polar cap, but mainly between the auroral zone and the equator. But though the magnetic field of this current-system was regarded as being "in entire agreement" with the observed diurnal magnetic-storm variations (as analyzed in my papers [9, 11, 12]), this view seems untenable, because the strongest currents along the auroral zone are usually westward, not eastward, and attain their maximum *after*, and not *before* midnight, though there are strong eastward currents at 17^h or 18^h.

(9) The theory of magnetic storms developed by Ferraro [13] and myself does not as yet offer any suggestion as to the detailed cause of the polar current-systems and their magnetic field. In view of the above criticism of the ultra-violet light theory of this part of a magnetic storm, the only remaining possibly admissible suggestion as to the production of the polar current-system seems to be one that I proposed very tentatively [11] in 1927. It is that there is a general horizontal drift of air, at high levels, across the polar cap, more or less parallel to the plane of the twilight circle; this drift may always be present, or may be intensified by and during the entry of the corpuscles from outside the atmosphere into the auroral regions. The observed concentration of the electric currents along the auroral zones, shown in the diagrams [12] I prepared in 1935, would on this view be due to the specially intense ionization along the auroral zone and, to a less extent, over the polar cap within the zone. It is not certain, however, without mathematical examination, that the suggested dynamo-action by a horizontal air-drift across this geographical distribution of ionization and conductivity would produce a current-system of the required type. It seems clear, however, from the fact that the current is in opposite directions along different parts of the auroral zone, that no "universal" theory like that of diamagnetism or magnetic-gravitational drift-currents can give a general explanation of the polar current-system.

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LETTERS TO EDITOR

PROVISIONAL SUNSPOT-NUMBERS FOR NOVEMBER AND DECEMBER, 1937, AND JANUARY, 1938

(Dependent alone on observation at Zürich Observatory and its station at Arosa)

Day	November	December	January
1	104	14	. . .[a]
2	. . .	*W*33[c]	*E*109[c]
3	103[aa]	. . .	*W* 86[c]
4	67	. . .	76
5	*W*68[c]	55	80[d]
6	49	. . .	. . .[a]
7	34[d]	. . .	*E*102[c]
8	47[d]	. . .	. . .
9	*M*. . .[c]	. . .	59(?)
10	*E*. . .[c]	56	92
11	79	*E*72[c]	98[ad]
12	83	70	. . .[d]
13	100[ab]	*M*107[c]	106
14	106	*M*112[acd]	111
15	74	*W*141[ac]	118(?)
16	69	*E*155[c]	134
17	*E*. . .[c]	. . .	. . .[b]
18	90[d]	109	110[b]
19	. . .	124[a]	*E*104[c]
20	82	107[b]	*M*. . .[c]
21	60	86	. . .[a](?)
22	. . .	*E*90[cd]	122
23	58[a]	*E*107[c]	. . .
24	. . .	. . .	108
25	*M*. . .[c]	. . .[a]	94
26	*M*70[c]	. . .	76[a]
27	96	125[aa]	*W* 67[cd]
28	64	103[a]	76
29	68	*M*113[c]	59
30	47	*M*111[c]	. . .[d]
31		112[ad]	76
Means......	73.5	95.3	93.8
No. days....	22	21	22

Mean for quarter[e] October to December, 1937: 98.1 (71 days)
Mean for year 1937: 116.3 (321 days)

[a]Passage of an average-sized group through the central meridian.
[b]Passage of a large group or spot through the central meridian.
[c]New formation of a group developing into a middle-sized or large center of activity: *E*, on the eastern part of the Sun's disc; *W*, on the western part; *M*, in the central-circle zone.
[d]Entrance of a large or average-sized center of activity on the east limb.
[e]The mean value for quarter April to June 1937 should read "*120.5* (*87 days*)" instead of "*130.4* (*90 days*)" as on page 310 of volume 42.

EIDGEN. STERNWARTE,
Zürich, Switzerland

W. BRUNNER

NOTE ON SOLAR ERUPTION OF OCTOBER 1, 1937, AT WATHEROO MAGNETIC OBSERVATORY

Between $11^h\,46^m$ and $11^h\,49^m$, 120° east meridian time, October 1, 1937, echoes from the ionosphere faded out at Watheroo. Observations with the spectrohelioscope were immediately started and it was found that a solar eruption in the large sunspot-group (approximate position, 12° south, 35° east) had occurred between the end of the preceding observation period at $11^h\,40^m$ and the resumption of observations at 12^h. The solar activity was judged to be of importance 3 at 12^h, falling off gradually until normal conditions again prevailed at about 14^h. Further ionospheric observations failed to show any echoes between 3.2 mc/sec and 11.6 mc/sec until $13^h\,50^m$ when echoes were again seen on 4.8 mc/sec, being weak until $14^h\,20^m$. The solar eruption had returned to an importance of less than 1 by 14^h.

The eruption was accompanied by identified changes in earth-potentials and terrestrial-magnetic elements. There was an increase of 5 mv/km in the north-south earth-potentials and a decrease of 1.5 mv/km in the east-west earth-potentials. A normal condition was again present by about 14^h. The magnetic records showed a decrease of 55.6 gammas in vertical intensity, an increase of 10.7 gammas in horizontal intensity, and a decrease of $4'.7$ in declination. The Mitchell vertical-intensity inductometer showed an identified movement beginning at $11^h\,53^m$. The disturbance of magnetic elements lasted some 10 to 15 minutes.

J. W. Green, S. L. Seaton, T. K. Hogan,
L. Prior, N. Chamberlain

Watheroo Magnetic Observatory,
Watheroo, Western Australia,
October 18, 1937

PROVISIONAL SOLAR AND MAGNETIC CHARACTER-FIGURES, MOUNT WILSON OBSERVATORY OCTOBER, NOVEMBER, AND DECEMBER, 1937

Greenwich mean time						Range hor. int.
Beginning			Ending			
1937	*h*	*m*	*d*	*h*	*m*	γ
Oct. 3	11	19	4	23	..	226
7	5	20*	8	20	..	141
9	6	36	10	18	..	129
11	2	..	13	1	..	146
Nov. 28	3	..	30	22	..	127
Dec. 23	8	..	23	21	..	131

*Sudden commencement.

An exceptionally large active group in latitude 9° north crossed the solar disk from September 28 to October 10. It extended over an area about 20° long and 8° wide, and on October 4, when it crossed the central meridian, the center of the solar disk was within its boundaries.

Day	October 1937 K_2 A	K_2 B	$H\alpha B$ A	$H\alpha B$ B	$H\alpha D$ A	$H\alpha D$ B	No. groups	Mag'c char.
1	5	4	4	4	3	1	12	1
2	...	...	...	...	...	...	12	0.5
3	...	...	...	...	...	...	...	1
4	5	5	4[c]	4	3	2	12[e]	1.5
5	5	4	4[c]	4	3	2	13	0
6	4	4	4	4[d]	3	2	9	0
7	4	4	4	4	4	2	10	1
8	4	4	4	4[d]	4	3	12	1
9	3	3	4	4	3	1	12[b]	1
10	3	3	3	3	3	2	14	1
11	3	3	3	4	2	3	12[i]	1.5
12	3	2	3	2	2	1	12[f]	1
13	3	2	3	2	1	1	10	0.5
14	...	...	...	...	...	...	...	0.5
15	...	...	...	...	...	...	9	0.5
16	3	4	3	3	1	1	8[j]	0
17	3	3	3	3	1	1	11	0
18	3	3	3	3	1	1	12	0
19	4	3	4	3	2	1	12	0
20	4	3	3	3	2	1	8	0
21	3	2	3	2	2	1	8	0
22	4	3	4	3	3	2	8	0.5
23	3	3	3	3	3	2	5	0.5
24	4	3	3	3	3	3	7[b]	1
25	4	4	3	3	3	3	9	0.5
26	4	3	...	...	...	...	7[f]	1
27	4	3	...	...	...	...	7	0.5
28	4	3	4	3	3	1	8	0.5
29	5	4	4	4	3	2	9[b]	0
30	5	5	4	4	4	2	11	...
31	...	...	...	...	...	...	...	0
Mean	3.8	3.3	3.5	3.3	2.6	1.7	10.0	0.6

Day	November 1937 K_2 A	K_2 B	$H\alpha B$ A	$H\alpha B$ B	$H\alpha D$ A	$H\alpha D$ B	No. groups	Mag'c char.
1	5	5	...	...	...	...	10	0
2	5	4	5	4	4	1	11	0
3	5	4	5	4	4	2	10[e]	0
4	4	4	4	4[d]	4	3	11	0
5	4	4	4	3	4	3	7	0
6	...	...	...	...	...	...	...	0
7	3	3	3	3	4	2	5	0
8	3	3	3	3	3	1	5	0.5
9	3	3	3	3	3	2	6	0.5
10	...	...	...	...	...	...	5	0
11	...	...	...	...	...	...	...	0.5
12	4	4	4	4	2	2	7	0
13	4	4	4	4	2	2	8	0
14	3	3	3	3	2	1	7[h]	0
15	3	3	3	3	2	1	8	0
16	3	3	3	3	3	1	8	0
17	...	...	...	...	...	...	...	0
18	...	...	3	3	3	1	9	1
19	3	2	...	...	...	...	8	0.5
20	4	3	3	3[d]	3	2	6	0.5
21	3	3	3	3	4	3	9	0.5
22	4	4	4	4	3	2	10	1
23	4	4	4	4	4	3	8	0.5
24	...	...	...	...	...	...	6	0.5
25	4	4	...	...	...	...	6	0
26	4	4	4[c]	4	3	2	10	0
27	4	4	4	4	3	2	8	0
28	3	3	3	3	4	3	9	0.5
29	3	4	3	3	4	3	8	1
30	3	3	3	3	5	4	5	1
31								
Mean	3.7	3.5	3.5	3.4	3.3	2.1	7.8	0.3

Day	December 1937 K_2 A	K_2 B	$H\alpha B$ A	$H\alpha B$ B	$H\alpha D$ A	$H\alpha D$ B	No. groups	Mag'c char.
1	...	...	...	...	...	...	...	0.5
2	...	...	...	...	...	...	7	0.5
3	...	...	...	...	...	...	5	0
4	2	3	2	3	4	1	4	0
5	2	2	2	2	4	1	5	0
6	2	2	2	2	3	1	7	0
7	2	2	3	2	2	1	8	0.5
8	...	...	...	...	...	...	...	0
9	...	...	...	...	...	...	...	0
10	...	...	...	...	...	...	...	0
11	...	...	...	...	...	...	...	0.5
12	...	...	...	...	...	...	4	0
13	3	3	3[c]	3	2	1	6	0
14	3	4	3	4	2	1	9[f]	0
15	...	...	...	...	...	...	11[i]	0
16	3	3	3	3	2	3	10	0
17	3	1	3	1	3	3	9	0
18	3	2	3	2	4	4	7	0.5
19	...	...	...	...	...	...	...	1
20	...	...	...	...	...	...	...	0.5
21	...	...	...	...	...	...	...[i]	0
22	3	3	3	3	5	2	8	0.5
23	...	...	...	...	...	...	...	1
24	4	3	4	3	4	4	11	0.5
25	4	4	4	4	4	4	9[g]	...
26	...	...	...	...	...	...	...	...
27	4	4	4	4	3	2	7[h]	...
28	3	3	4	4	3	2	9	0
29	3	3	3	3	3	3	11[b]	0
30	...	...	3	3	3	3	9	0
31	...	...	...	...	...	...	9	0
Mean	2.9	2.8	3.1	2.9	3.2	2.2	7.9	0.2

NOTE—For an explanation of these tables see this JOURNAL, **35**, 47-49 (1930).

?Indicates an uncertain value which should be given low weight.

The character-figures of solar phenomena are estimated from the spectroheliograms which are made with a 2-inch solar image, usually in the early morning. The very bright chromospheric eruptions are reported in these notes if observed at any time during the day.

[a, b] Formation of a new group which later developed to average size or larger; (*a*) less than 30° from the center of the disc, (*b*) more than 30° from the center of the disc.

Following the large group were several other groups which with it formed a stream of spots over 100° long. Five magnetic storms, the first of which was reported in the last issue of the JOURNAL, occurred between September 30 and October 13. It is possible that all of these storms were due to the activity of the large group, although the other groups in the stream may also have had some effect.

The most active group on the Sun at the time of the storm of December 23 crossed the central meridian on December 21, 29° north of the center of the solar disk.

CARNEGIE INSTITUTION OF WASHINGTON,
MOUNT WILSON OBSERVATORY,
Pasadena, California

SETH B. NICHOLSON
ELIZABETH E. S. MULDERS

AMERICAN *URSI* BROADCASTS OF COSMIC DATA[1], OCTOBER TO DECEMBER, 1937, WITH AMERICAN MAGNETIC CHARACTER-FIGURE C_A, JANUARY TO MARCH, 1937, AND NOVEMBER, 1937, TO JANUARY, 1938

The data for terrestrial magnetism, sunspots, and solar constant are the same as given in previous tables.

The first three columns of the Table give (1) the magnetic character according to the scale 0-2 of the International Commission of Terrestrial Magnetism and Atmospheric Electricity, (2) the type featuring the day other than normal by the letters b, p, o, and i for days marked by bay, rapid pulsations, long-period oscillations, and irregular oscillations, respectively, and (3) the hour and minute of Greenwich mean time marking the beginning of a storm, the end of the storm being indicated in the foot-note to the Table. The next two columns give the data relating to sunspots: (1) the number of groups of spots and (2) the total number of spots. It is to be noted that sunspot-numbers such as those from Zürich can be obtained from the number of groups and spots given in the Table by the formula $N=k\ (10g+s)$, where the mean value of k for Mount Wilson was 0.53 during 1936; during 1937 this value varied from 0.47 to 0.66, with an average value of 0.53.

Mount Wilson Observatory is now supplying corrections and additions to the sunspot-data which are broadcast in the *URSI*gram. So far as possible, these additional and corrected values will be used in this tabular summary and will be designated as such in foot-notes to the Table.

Beginning January 1, 1934, the magnetic information of the *URSI*-gram is for Cheltenham, Maryland, instead of Tucson, Arizona. In addition to this change in observatory, beginning November 1, 1937, the data cover the 24 hours of the Greenwich day ending at 19^h, 75° west meridian mean time instead of the 24 hours ending at 8^h, 75° west meridian mean time.

[1]For previous announcements see Terr. Mag., **35**, 184-185 and 252-253 (1930); **36**, 54, 141, 258-259, and 358-360 (1931); **37**, 85-89, 189-192, 408-411, and 484-487 (1932); **38**, 60-63, 148-151, 262-265, 335-339 (1933); **39**, 73-77, 159-163, 244-247, 353-356 (1934); **40**, 111-115, 220-222, 334-336, 449-452 (1935); **41**, 85-87, 207-209, 315-317, 407-409 (1936); **42**, 89-91, 207-209, 316-319, and 411-415 (1937).

Summary American URSI daily broadcasts of cosmic data, October to December, 1937

Greenwich date	October Magnetism Character	Type	GMT beginning disturbance (h m)	Sunspot Groups	Number	November Magnetism Character	Type	GMT beginning disturbance (h m)	Sunspot Groups	Number	December Magnetism Character	Type	GMT beginning disturbance (h m)	Sunspot Groups	Number
1	1	*i*	.. ..	12	215	0	...	.. ..	10	165	1	*i*	.. ..	...	...
2	0	...	.. ..	12	170	0	...	.. ..	11	130	0	...	.. ..	7	20
3	0	*b*	11 18	...	...	0	...	.. ..	10*	190	0	...	.. ..	5	10
4	2	*i*	.. ..	12*	230	0	...	.. ..	11	165	0	...	.. ..	4	10
5	0	...	.. ..	13	225	0	...	.. ..	7	130	0	...	.. ..	5	20
6	0	...	.. ..	9	215	0	...	.. ..	...	...	0	...	.. ..	7	35
7	0	*i*	13 30	10*	245	0	...	.. ..	5	25	0	...	.. ..	8	65
8	1	*i*	.. ..	12*	220	0	...	.. ..	5	55	0	...	.. ..	...	...
9	1	*i*	06 35	12*	210	0	...	.. ..	6	80	0	...	.. ..	...	...
10	1	*i*	.. ..	14*	150	0	...	.. ..	...	...	0	...	.. ..	...	...
11	1	*i*	.. ..	12	195	0	...	.. ..	...	...	0	...	.. ..	...	...
12	1	*i*	08 00	12	160	0	...	.. ..	7	125	0	...	.. ..	...	...
13	1	*i*	.. ..	10	180	0	...	.. ..	8	115	0	...	.. ..	6	65
14	0	...	.. ..	...	...	0	...	.. ..	7	95	0	...	.. ..	9	75
15	1	*i*	04 54	9	115	0	...	.. ..	8	85	0	...	.. ..	11	155
16	0	...	.. ..	8	150	0	...	.. ..	8	65	0	...	.. ..	10	140
17	0	...	.. ..	11	125	0	...	.. ..	...	...	0	...	.. ..	9	170
18	0	...	.. ..	12	190	1	*i*	.. ..	9	75	1	...	.. ..	7	145
19	0	...	.. ..	12	140	0	...	.. ..	8	95	1	...	.. ..	...	...
20	0	...	.. ..	8	95	0	...	.. ..	6	40	1	...	.. ..	...	...
21	0	...	.. ..	8	80	0	...	.. ..	9	50	0	...	.. ..	...	...
22	0	*o*	18 00	8	70	0	...	.. ..	10	70	0	...	.. ..	8	120
23	1	*o*	.. ..	5	110	1	*i*	.. ..	8	65	1	*i*	08 02	...	...
24	1	...	.. ..	7	105	1	...	.. ..	...	...	0	...	.. ..	11	155
25	0	...	.. ..	9	125	0	...	.. ..	6	20	0	...	.. ..	9	235
26	1	*i*	01 45	7	115	0	...	.. ..	10	55	0	...	.. ..	...	...
27	1	*b*	.. ..	7	125	0	...	.. ..	8	50	0	...	.. ..	7	245
28	0	...	.. ..	8	185	1	*i*	.. ..	9	45	0	...	.. ..	9	205
29	0	...	.. ..	9	170	1	*i*	.. ..	8	30	0	...	.. ..	11	245
30	0	...	.. ..	11	185	1	*i*	.. ..	5	25	0	...	.. ..	9	140
31	0	...	.. ..	...	...						0	...	.. ..	...	...
Mean	0.5	...	....	...	...	0.2	...	....	...	...	0.2	...	....	...	...

*Revision of value originally broadcast.

Greenwich mean time for ending of storms: 24^h, October 1; 13^h, October 4; 20^h, October 8; 1^h, October 12; 1^h, October 13; 2^h 10^m, October 16; 12^h, October 23; 13^h, October 27; 20^h, December 23.

In accordance with information received from Dr. C. G. Abbot, Secretary of the Smithsonian Institution on March 6, 1937, solar-constant values were discontinued owing to important change in methods.

The data for the table of Kennelly-Heaviside Layer heights which is self-explanatory are supplied by the National Bureau of Standards.

As set forth in this Journal for June, 1937, "The Department of

Kennelly-Heaviside Layer heights, Washington, D. C., October to December, 1937
(Nearest hour, Greenwich mean time, of all observations is 17)

Date	Freq.	Ht.	Date	Freq.	Ht.	Date	Freq.	Ht.	Date	Freq.	Ht.
1937	*kc/sec*	*km*	*1937*	*kc/sec*	*km*	*1937*	*kc/sec*	*km*	*1937*	*kc/sec*	*km*
Oct. 6	2,500	120	Oct. 27	4,400	250	Nov. 17	11,000	340	Dec. 8	11,200	570
" "	3,500	160	" "	5,400	270	" "	11,800	330	" "	11,800	230
" "	3,600	*	" "	7,000	280	" "	11,800	390	" "	12,200	470
" "	3,750	290	" "	8,600	310	" "	12,400	360	" "	12,400	*
" "	4,100	240	" "	10,200	330	" "	12,400	470	" 15	2,500	120
" "	4,400	240	" "	11,800	360	" "	13,200	460	" "	3,300	180
" "	5,400	260	" "	11,800	410	" "	13,400	*	" "	3,320	330
" "	7,800	290	" "	13,000	420	" 24	2,500	120	" "	3,500	230
" "	9,400	320	" "	13,000	600	" "	3,180	180	" "	4,400	230
" "	11,000	350	" "	14,000	570	" "	3,200	290	" "	5,400	230
" "	11,800	380	" "	14,200	*	" "	3,400	230	" "	7,000	250
" "	11,800	420	Nov. 3	2,500	110	" "	4,400	240	" "	9,400	280
" "	12,600	410	" "	3,300	140	" "	7,000	250	" "	10,600	320
" "	12,600	550	" "	3,550	190	" "	9,400	260	" "	10,600	350
" "	13,400	590	" "	3,580	310	" "	11,000	300	" "	11,400	380
" "	13,600	*	" "	3,900	250	" "	12,600	320	" "	11,400	530
" 13	2,500	120	" "	4,400	240	" "	13,400	350	" "	11,800	450
" "	3,500	190	" "	4,600	230	" "	13,400	420	" "	12,200	570
" "	3,600	*	" "	5,400	240	" "	14,000	360	" "	12,400	*
" "	3,650	300	" "	7,000	260	" "	14,000	390	" 22	2,500	120
" "	4,000	230	" "	9,400	300	" "	14,400	380	" "	3,300	170
" "	5,400	240	" "	11,000	320	" "	14,800	480	" "	3,350	340
" "	7,000	280	" "	12,600	340	" "	15,000	*	" "	3,600	240
" "	8,600	290	" "	13,400	350	Dec. 1	2,500	120	" "	4,400	240
" "	10,200	320	" "	13,400	430	" "	3,000	130	" "	7,000	250
" "	11,800	360	" "	14,000	380	" "	3,160	270	" "	9,400	270
" "	11,800	410	" "	14,000	500	" "	3,400	220	" "	11,000	300
" "	13,200	430	" "	14,800	490	" "	3,900	260	" "	12,600	300
" "	13,200	590	" "	15,000	*	" "	4,400	250	" "	12,600	350
" "	14,000	560	" 10	2,500	100	" "	4,600	240	" "	13,400	350
" "	14,200	*	" "	4,400	100	" "	7,000	260	" "	13,400	500
" 20	2,500	120	" "	5,400	110	" "	9,400	280	" "	13,800	410
" "	3,500	170	" "	5,400	260	" "	11,000	300	" "	14,000	480
" "	3,550	*	" "	7,000	110	" "	12,600	310	" "	14,200	*
" "	3,600	290	" "	7,000	270	" "	12,600	360	" 29	2,500	120
" "	3,900	230	" "	9,400	280	" "	13,800	370	" "	3,300	150
" "	4,400	240	" "	11,000	320	" "	13,800	490	" "	3,320	310
" "	5,400	250	" "	12,000	320	" "	14,600	470	" "	3,500	230
" "	7,800	270	" "	12,000	370	" "	14,800	*	" "	4,400	250
" "	9,400	300	" "	13,000	370	" 8	2,500	130	" "	5,400	250
" "	11,000	330	" "	13,000	520	" "	3,100	200	" "	8,600	270
" "	12,000	330	" "	13,800	480	" "	3,150	350	" "	10,200	300
" "	12,000	390	" "	14,000	*	" "	3,300	220	" "	10,200	340
" "	13,000	380	" 17	2,500	120	" "	3,500	240	" "	10,600	320
" "	13,000	550	" "	3,000	130	" "	4,400	230	" "	10,600	360
" "	14,000	540	" "	3,200	150	" "	4,600	240	" "	11,000	340
" "	14,200	*	" "	3,250	370	" "	7,000	270	" "	11,000	450
" 27	2,500	130	" "	3,600	220	" "	9,400	300	" "	11,400	380
" "	3,200	140	" "	4,600	240	" "	9,400	320	" "	11,800	540
" "	3,500	180	" "	7,000	260	" "	11,000	340	" "	12,000	*
" "	3,550	280	" "	9,400	300	" "	11,000	440			
" "	3,800	240	" "	11,000	320	" "	11,200	380			

* = No value obtained.

American magnetic character-figure C_A for Greenwich half-days based on reports from Cheltenham, Honolulu, Huancayo, San Juan, Sitka, Tucson, and Watheroo for January to March, 1937

Day	January		February		March	
	0^h-12^h	12^h-24^h	0^h-12^h	12^h-24^h	0^h-12^h	12^h-24^h
1	0.0	0.0	0.4	0.1	0.6	1.1
2	0.1	0.3	0.0	0.5	0.9	0.5
3	0.3	0.0	1.6	1.4	0.0	0.0
4	0.1	0.1	0.6	0.8	0.0	0.2
5	0.0	0.0	0.6	0.7	1.1	1.4
6	0.0	0.0	0.6	0.4	0.4	0.1
7	0.1	0.9	0.1	0.0	0.0	0.1
8	0.2	0.1	0.0	0.1	0.0	0.1
9	0.7	1.0	0.5	1.0	0.2	0.2
10	0.9	0.8	0.6	0.8	0.2	0.2
11	0.5	0.5	0.4	0.4	0.1	0.0
12	0.1	0.6	0.1	0.5	0.0	0.0
13	0.2	0.1	0.4	0.7	0.2	0.8
14	0.1	0.1	0.1	0.2	1.0	0.3
15	0.0	0.0	0.1	0.3	0.8	1.1
16	0.0	0.0	0.3	0.3	0.3	0.2
17	0.0	0.1	0.1	0.4	0.4	0.3
18	0.0	0.0	0.0	0.6	0.1	0.1
19	0.0	0.0	0.8	1.2	0.0	0.0
20	0.0	0.2	0.8	0.8	0.0	0.1
21	0.3	0.6	0.7	0.6	0.0	0.4
22	0.1	0.0	0.3	0.5	0.8	1.2
23	0.0	0.0	0.0	0.0	0.6	0.4
24	0.0	0.0	0.4	0.1	0.1	0.5
25	0.0	0.0	0.3	0.2	0.3	0.1
26	0.0	0.0	0.1	0.0	0.1	0.7
27	0.7	0.7	0.0	0.1	1.0	1.1
28	0.4	0.3	0.1	0.1	0.7	0.3
29	0.4	0.0			0.1	0.2
30	0.0	1.1			0.2	0.6
31	0.1	0.0			1.7	0.9
Means	0.2	0.2	0.4	0.5	0.4	0.4
	0.2		0.4		0.4	

Terrestrial Magnetism and United States Coast and Geodetic Survey with the cooperation of the United States Army and United States Navy communication-services and several amateur radio stations have undertaken to supply an American character-figure based upon the reports of the seven American-operated observatories—those of the Department of Terrestrial Magnetism at Huancayo in Peru and at Watheroo in Western Australia, and those of the United States Coast and Geodetic Survey at Cheltenham (Maryland), Honolulu (Hawaii), San Juan (Puerto Rico), Sitka (Alaska), and Tucson (Arizona)." This character-figure is being designated C_A. In order to have a complete record of C_A for the year 1937, the Department of Terrestrial Magnetism and the

United States Coast and Geodetic Survey have assigned character-numbers for the seven observatories covering the period January 1 to March 12, 1937. The values for January to March, 1937, and for November, 1937, to January, 1938, are given in the accompanying Tables.

American magnetic character-figure C_A for Greenwich half-days based on reports from Cheltenham, Honolulu, Huancayo, San Juan, Sitka, Tucson, and Watheroo for November, 1937, to January, 1938

Day	1937				1938	
	November		December		January	
	0^h-12^h	12^h-24^h	0^h-12^h	12^h-24^h	0^h-12^h	12^h-24^h
1	0.0	0.2	0.8	0.4	0.5	0.6
2	0.3	0.4	0.5	0.1	0.4	0.6
3	0.1	0.0	0.1	0.1	0.2	0.4
4	0.0	0.0	0.0	0.1	0.6	1.2
5	0.0	0.1	0.0	0.3	0.5	0.1
6	0.0	0.0	0.2	0.4	0.1	0.6
7	0.1	0.6	0.6	0.7	0.5	0.7
8	0.6	0.7	0.4	0.6	1.1	0.2
9	0.5	0.5	0.3	0.4	0.5	0.2
10	0.1	0.3	0.4	0.6	0.0	0.0
11	0.3	0.5	0.5	0.4	0.1	0.0
12	0.3	0.4	0.0	0.1	0.2	0.7
13	0.1	0.2	0.1	0.0	1.4	0.6
14	0.1	0.1	0.0	0.1	0.2	0.5
15	0.0	0.0	0.1	0.3	0.4	0.5
16	0.0	0.1	0.2	0.1	0.4	1.4
17	0.1	0.5	0.1	0.3	1.9	2.0
18	0.9	1.2	0.5	0.9	1.0	1.2
19	0.8	1.1	1.0	0.8	0.8	0.9
20	0.6	0.6	0.4	0.6	0.8	1.1
21	0.2	0.3	0.1	0.2	1.2	1.0
22	0.6	0.8	0.3	0.1	2.0	1.9
23	0.8	0.9	0.5	1.1	0.7	0.6
24	0.7	0.6	0.1	0.6	0.8	0.7
25	0.1	0.1	0.4	0.4	0.6	2.0
26	0.0	0.1	0.6	0.4	1.7	1.0
27	0.1	0.6	0.1	0.1	0.2	0.6
28	0.6	0.8	0.1	0.1	0.1	0.4
29	0.8	1.1	0.0	0.0	0.2	0.6
30	0.7	1.0	0.1	0.1	0.1	0.3
31			0.1	0.6	0.5	0.1
Means	0.3	0.5	0.3	0.4	0.6	0.7
	0.4		0.3		0.7	

H. F. Johnston

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

AVERAGES OF CRITICAL FREQUENCIES AND VIRTUAL HEIGHTS OF THE IONOSPHERE, OBSERVED BY THE NATIONAL BUREAU OF STANDARDS, WASHINGTON, D. C., NOVEMBER, 1937, TO JANUARY, 1938[1]

The following ionosphere data are in continuation of those published for 1934-36 in this Journal[2]. The symbols used are:

h_E = E-region virtual height, kilometers (lowest measured height)

h_{F_1} = F_1-region virtual height, kilometers (lowest measured height)

h_{F_2} = F_2-region virtual height, kilometers (lowest measured height)

f_E = E-region critical frequency, kilocycles per second, ordinary ray

$f^o{}_{F_1}$ = F_1-region critical frequency, kilocycles per second, ordinary ray

$f^x{}_{F_2}$ = F_2-region critical frequency, kilocycles per second, extraordinary ray

EST = Eastern standard time (75° west meridian time); add 5 hours for Greenwich time

♯ = Manual measurements

* = Less than ten measurements with automatic recorder

[1]Communicated by the director of the National Bureau of Standards of the United States Department of Commerce.

[2]T. R. Gilliland, S. S. Kirby, N. Smith, and S. E. Reymer, Terr. Mag., **41**, 379-388 (1936).

Table 1—*Ionosphere data, National Bureau of Standards, Washington, D. C.*

EST	h_E	h_{F_1}	h_{F_2}	f_E	$f^o{}_{F_1}$	$f^x{}_{F_2}$	h_E	h_{F_1}	h_{F_2}	f_E	$f^o{}_{F_1}$	f^x
h			*November*[a]						*December*[a]			
00			290			6440			310			4
01			283			6230			312			5
02			292			6140			303			5
03			290			5900			287			5
04			287			5500			286			4
05			295			5080			293			4
06			300	1050♯		5070	...		299	1000♯		4
07			248	1850		7280	...		272	1360♯		5
08			235	2410		9820	...		226	2180		8
09	120		233	2943		11550♯	120*		230	2690		10
10	123		229	3206		12600♯	124		229	3090		12
11	120		230	3350		13880♯	123		231	3220		13
12	121		233	3380		14270♯	120		228	3260		13
13	121		235	3320		14280♯	121		228	3210		13
14	122		235	3170		14100♯	121		231	3030		13
15	125		237	2860		13900	120*		235	2730		12
16			236	2290		13400	...		230	2200		12
17			231	1560♯		12210	...		225	1480♯		11
18			241			10810			233			9
19			243			9530			233			8
20			251			8250			245			6
21			266			7350			275			5
22			279			6830			286			5
23			288			6550			289			5

[a]F-layer stratification not in evidence during November and December, 1937.

TABLE 1—*Ionosphere data, National Bureau of Standards, Washington, D. C.—Continued*

ST	h_E	h_{F_1}	h_{F_2}	f_E	$f^\circ_{F_1}$	$f^x_{F_2}$
h			*January, 1938*			
00			309			5280
01			314			5250
02			308			5200
03			305			5010
04			307			4685
05			306			4340
06			310	1050#		4360
07			280	1510#		5300
08			234	2340#		8060
09	127*		229	2770		9800
10	125		229	3120		11370#
11	124		229	3310		12770#
12	124		226	3385		12340#
13	122		227	3335		12480#
14	121		230	3220		12600#
15	126		238	2978		12650#
16			237	2510		12250#
17			232	1780#		11500#
18			237			9380
19			239			8290
20			247			7270
21			276			6340
22			286			5810
23			294			5620

Notes on January data

No *F*-layer stratification in evidence except during severe ionospheric storms on January 17, 22, and 25.

At the following times *F*- or F_2-layer critical frequencies were not included because of poor definition or no reflections:
Jan. 13—00:00, 01:00, 02:00, 03:00, 04:00, 05:00, 06:00, 07:00.
Jan. 22—02:00, 03:00, 04:00, 05:00, 06:00, 07:00, 08:00.
Jan. 25—17:00, 18:00, 19:00, 20:00, 21:00, 22:00, 23:00.
Jan. 26—00:00, 01:00, 02:00, 03:00, 04:00, 05:00, 06:00, 07:00.

At the following times *F*- or F_2-layer virtual heights were not included because of diffusion or lack of reflections:
Jan. 22—05:00, 06:00, 07:00, 08:00, 09:00, 10:00, 11:00.
Jan. 25—13:00, 14:00, 15:00, 16:00, 17:00, 18:00, 19:00, 20:00.
Jan. 26—05:00.

NATIONAL BUREAU OF STANDARDS,
UNITED STATES DEPARTMENT OF COMMERCE,
Washington, D. C.

ON THE LUNAR-DIURNAL VARIATION IN THE EARTH-CURRENTS

In my article printed in this JOURNAL, June 1937 (pp. 179-181), the values given in Table 2 for the lunar variation of the earth-current potential-gradient during the solar hours 20 to 5 at Ebro Observatory for the year 1910 (direction 25° west of north) are to be corrected as follows:

Hour	Main term L_2 in mv/km
20 to 21	$2.4 \sin (2t+21°)$
22 to 23	$2.4 \sin (2t+7°)$
0 to 1	$1.6 \sin (2t+15°)$
2 to 3	$1.2 \sin (2t+355°)$
4 to 5	$1.4 \sin (2t+36°)$

The value of L_2 for the hours 20 to 5 is $L_2=1.8 \sin (2t+15°)$ mv/km and for the day-hours 6 to 19 is $L_2=2.2 \sin (2t+44°)$ mv/km. The amplitude of L_2 for the night-hours is only a little smaller than that for the day-hours and the phase-angles for the two periods are not much different. As the amplitudes of L_2 for both night and day are of good accuracy, it is evident that the amplitudes mentioned are not much different and it might seem desirable to reconsider theories on earth-currents and earth-current measurements.

Copenhagen, Denmark,
February 7, 1938

J. EGEDAL

NOTE ON IONOSPHERIC DISTURBANCE AT WATHEROO MAGNETIC OBSERVATORY, JUNE 23, 1937

Ionospheric observations of June 23, 1937, showed a disturbance of the F_2-region in the form of a rapid increase of ionization lasting for about 30 minutes. There was no apparent simultaneous magnetic effect. At 10:15, 120° east meridian time, a distinct weakening of echoes was observed. This was not any characteristic of the transmitter because normally echoes are stronger at six mc per sec— the frequency observed at 15 minutes past the hour.

An analysis of the trace showed that the ordinary critical frequency of the F_2-region was 12.6 mc per sec at 10:49 and its extraordinary critical frequency was less than 13.2 mc per sec at 10:52. Hence $(f^x - f^o)$ was less that 0.6 mc per sec.

For the magnetic field at Watheroo the separation is normally about 0.7 mc. Therefore $(dN\ dt)$ between 10:49 and 10:52 was negative. From this it is apparent that maximum ionization occurred before 10:49 and probably after 10:15.

The critical frequencies for the observations at 9^h and 11^h were 10.2 and 10.6 mc per sec, respectively. The mean ionization for these two hours would be $1.35\times10^{+6}$ electrons per cc. The ionization at 10:49 was $1.98\times10^{+6}$ electrons per cc. This shows an increase of about 50 per cent. Therefore the maximum ionization may have been more than 50 per cent greater than normal during this fluctuation.

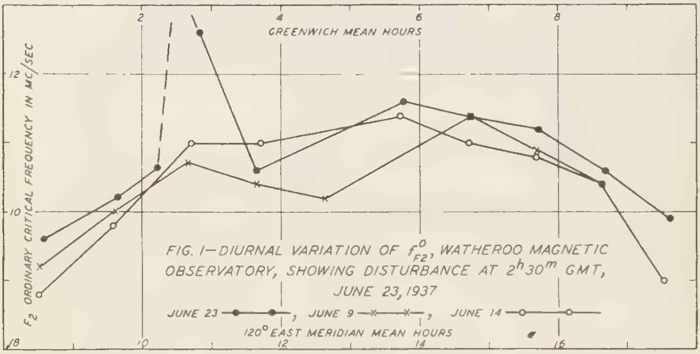

FIG. 1—DIURNAL VARIATION OF f^o_{F2}, WATHEROO MAGNETIC OBSERVATORY, SHOWING DISTURBANCE AT $2^h 30^m$ GMT, JUNE 23, 1937

Figure 1 shows the diurnal-variation curve of $fF_2°$ for this day together with those of other days in June to serve as control.

Sudden increases or decreases of ionization of F_2-region have been frequently observed at Watheroo. This short fluctuation is of greater than usual amplitude and therefore seems worthy of attention.

Watheroo Magnetic Observatory S. L. Seaton and T. Kevin Hogan
Watheroo, Western Australia

PRINCIPAL MAGNETIC STORMS

Sitka Magnetic Observatory
October to December, 1937[1]

(*Latitude 57° 03'.0 N., longitude 135° 20'.1 or 9h 01m.3 W. of Gr.*)

September 30-October 1 A slight magnetic disturbance began abruptly at 13h 46m GMT, September 30, with a sudden increase of 40 gammas in *H* and a decrease of 8' in east declination. The elements were mildy disturbed with short-period vibrations superimposed on irregular oscillations until about 24h GMT, October 1. Ranges: *D*, 62'; *H*, 437 gammas; *Z*, 437 gammas.

October 3-5—A moderate storm began gradually at 11h 20m GMT, October 3, with a gradual decrease of 500 gammas in *H* during the succeeding two hours. During the next three hours there was a gradual recovery to normal values. During the five-hour period the elements moved with a short-period pulsating motion. At approximately 23h, October 3, *H* began increasing gradually to a value only slightly above normal, then from 02h 35m to 02h 55m, October 4, *H* increased approximately 400 gammas. The elements remained badly disturbed until 07h, with large irregular fluctuations superimposed on abnormally high numerical values of *H*; during this period *Z* had decreased and also east declination. From 07h to 24h, October 4, the trace was moderately disturbed. The storm ceased at 01h 30m, October 5, 1937. Ranges: *D*, 157'; *H*, 1200 gammas; *Z*, 975 gammas.

October 7-8—A slight disturbance began abruptly at 05h 21m GMT, October 7, with a decrease of 12 gammas in *H* during the first minute and then an increase of 52 gammas during the next two minutes. *D* and *Z* showed similar but smaller changes at the same time. The disturbance lasted until 20h, October 8. Ranges: *D*, 29'; *H*, 458 gammas; *Z*, 450 gammas.

October 9-12—A small storm began gradually at about 06h GMT, October 9. At 12h, *H* and *Z* had each decreased about 900 gammas and remained quite disturbed at this low value until 16h, at which time a pulsating motion at about normal values began. This motion continued until 06h 33m, October 10, when sudden increases of 380 gammas in *H*, and corresponding large changes in the other elements, marked the beginning of another period of great activity. After 13h the elements gradually returned to normal values. The general storminess continued through October 12. Ranges: *D*, 159'; *H*, 1175 gammas; *Z*, 930 gammas.

October 22-27—An extended period of magnetic disturbance began gradually at about 07h GMT, October 22 and continued through October 27. It was marked by its great number of large bays on which were superimposed short-period pulsations of small amplitude. Ranges: *D*, 46'; *H*, 336 gammas; *Z*, 482 gammas.

November 18-19 A minor disturbance began at about 02h GMT, November 18, with a gradual increase in the activity with short-period pulsations. The disturbance stopped about 24h, November 19. The generally disturbed conditions continued for the next several days. Ranges: *D*, 102'; *H*, 504 gammas; *Z*, 501 gammas.

[1]Communicated by the Director, United States Coast and Geodetic Survey.

November 27-December 1—At about $11^h 40^m$ GMT, November 27, a minor magnetic disturbance started. It slowly increased in intensity until midday on November 30; thereafter it began to subside and by 12^h, December 1, the disturbance had stopped. Ranges: *D*, 77′; *H*, 431 gammas; *Z*, 552 gammas.

December 18-19—A small disturbance began gradually at about 10^h GMT, December 18. The elements moved with short-period pulsations superimposed on large bays. The disturbance ended at 22^h, December 19. The trace however remained moderately disturbed until the beginning of the next storm. Ranges: *D*, 67′; *H*, 426 gammas; *Z*, 322 gammas.

December 23—A small magnetic storm began gradually at 08^h GMT, December 23. The trace was disturbed by short-period pulsations of relatively large amplitude during the interval from 12^h to 15^h, December 23. The storm then gradually diminished and ceased about 23^h, December 23. Ranges: *D*, 128′; *H*, 1196 gammas; *Z*, 922 gammas.

Robert E. Gebhardt, *Observer-in-Charge*

Cheltenham Magnetic Observatory
October to December, 1937[1]

(*Latitude 38° 44′.0 N., longitude 76° 50′.5 or $5^h 07^m.4$ W. of Gr.*)

October 3-4—A storm began abruptly at $11^h 19^m$ GMT, October 3, with an increase of 12 gammas in *H*. It progressed mildly with short-period oscillations until midnight of October 3. The storm then entered into a severe phase lasting about ten hours. During this time there were rapid changes of great amplitude and the extreme values of all three elements occurred about 06^h. Ranges: *D*, 77′; *H*, 370 gammas; *Z*, 350 gammas.

October 7-8—A mild storm began at $05^h 21^m$ GMT, October 7, with a rapid increase in *H* of 40 gammas in one minute. The most intense period of the storm was from 03^h to 08^h, October 8, and it ended at 20^h, October 8. Ranges: *D*, 42′; *H*, 152 gammas; *Z*, 181 gammas.

October 9-11—After a quiet period of several hours the field again became disturbed beginning at $06^h 36^m$ GMT, October 9. The perturbations were in general of short period. At 11^h, October 9, *H* began to decrease and it reached its minimum value at $15^h 13^m$. The field continued to be moderately disturbed until 01^h, October 11. The greatest activity of the storm occurred between 14^h and 16^h, October 11.

October 23-24—The elements were moderately disturbed from 22^h GMT, October 23 to 03^h, October 24. The disturbance was characterized by increased values of *Z*. Ranges: *D*, 15′; *H*, 72 gammas; *Z*, 75 gammas.

November 29—An abrupt beginning of a disturbance began at $11^h 05^m$ GMT, November 29. *D* decreased 2′.5 in west declination followed by an increase of 6′ in one minute; *H* increased 22 gammas and *Z* decreased slightly followed by an increase of 3 gammas in one minute.

December 23—A storm of moderate intensity began at $08^h 02^m$ GMT, December 23. The beginning was distinct but not abrupt after several days of quiet magnetic conditions. The first three hours of the storm were long-period oscillations, when suddenly at $10^h 48^m$ the character of

[1]Communicated by the Director, United States Coast and Geodetic Survey.

the storm changed to short-period oscillations superimposed on irregular perturbations. The storm ended at 23^h and was followed by quiet conditions. Ranges: D, 18′; H, 176 gammas; Z, 74 gammas.

ALBERT K. LUDY, *Observer-in-Charge*

TUCSON MAGNETIC OBSERVATORY
OCTOBER TO DECEMBER, 1937[1]

(*Latitude 32° 14′.8 N., longitude 110° 50′.1 or* $7^h\ 23^m.3$ *W. of Gr.*)

October 3-4—At $11^h\ 18^m$ GMT, October 3, H increased 25 gammas in three minutes. At the same time east declination decreased 2′. The elements continued moderately disturbed until 24^h, when H began to decrease rapidly. This was soon followed by large oscillations in H and D, lasting until 08^h, October 4. The larger oscillations also affected Z moderately. Except for minor disturbances of the saw-tooth variety and a low value of H, the storm ended at 08^h, but the elements were not entirely normal for about 19 hours later. The range of H for the storm was 233 gammas. The ranges of D and Z were scarcely larger than the normal diurnal ranges.

October 7-8—A moderate storm began sharply at $05^h\ 20^m$ GMT, October 7, with an increase in H of 34 gammas, D and Z being only very slightly disturbed. After about three hours the activity in H became insignificant. From about 19^h, October 7, to 10^h, October 8, there occurred a number of long, shallow bays, chiefly in H, the average value of which also decreased considerably below normal. The storm ended at 10^h, October 8.

October 9-10—A period of moderate disturbance began at $06^h\ 35^m$ GMT, October 9, and lasted until 18^h, October 10. Throughout this period the elements fluctuated through moderate amplitudes at short periods. During the middle half of the period the average value of H was also definitely below normal. Several shallow bays occurred between 03^h and 10^h, October 10. As is usual at this station, the disturbance was most pronounced in H, least in Z.

October 11—A moderate disturbance occurred on October 11, from about 10^h GMT to the end of the day. The outstanding feature of the storm was a sudden rise in H of 50 gammas at $13^h\ 40^m$, followed half an hour later by a drop of 132 gammas. Thereafter the disturbance consisted chiefly of two long bays in H.

JOHN HERSHBERGER, *Observer-in-Charge*

APIA OBSERVATORY
OCTOBER TO DECEMBER, 1937

(*Latitude 13° 48′.4 S., longitude 171° 46′.5 or* $11^h\ 27^m.1$ *W. of Gr.*)

October 1-13—A magnetic storm commenced at $13^h\ 44^m$ GMT, September 30, with a sudden increase of 20 gammas in H, 6 gammas in Z, and a slight decrease in the easterly declination. This marked the beginning of a disturbed period during which there appeared to be four phases of activity. From the maximum at $15^h\ 34^m$, September 30, H decreased through a range of 152 gammas to a maximum at $06^h\ 43^m$,

[1] Communicated by the Director, United States Coast and Geodetic Survey.

October 1. Another sudden increase of 22 gammas in H at $11^h 21^m$, October 3, was the beginning of more intense activity and the rapid decrease in H on October 4 resulted in a minimum which was too low to be recorded, but the measurable range was 225 gammas. Unfortunately the Z clock stopped on October 3 and the record October 3-4 was missed. There was a period on October 6 during which H, D, and Z showed rapid oscillations of small amplitude which were well defined between 17^h and 19^h. Conditions appeared to be approaching normal when another disturbance commenced abruptly at $05^h 21^m$, October 7. There was a range of 162 gammas in H associated with this storm. After a short lull, conditions again became disturbed on October 9 between 06^h and 07^h. The traces showed that the magnetic elements were relatively quiet by October 13 and there were no further disturbances of importance during the remainder of the quarter.

J. Wadsworth, *Director*

Huancayo Magnetic Observatory
October to December, 1937

(*Latitude 12° 02′.7 S., longitude 75° 20′.4 or $5^h 01^m.4$ W. of Gr.*)

October 3-4—A sudden commencement of relatively small amplitude occurred in all three elements at $11^h 22^m$ GMT, October 3. H decreased 2 gammas and then increased 17 gammas in two minutes. In the same interval D moved westerly 1′ and Z increased 5 gammas. The traces were very disturbed from this time until the end of October 4, a marked feature of the storm being a minimum bay in H from 00^h to 12^h, October 4.

October 5—At $17^h 06^m$ GMT, October 5, a sharp increase occurred in all elements, culminating at $17^h 10^m$ and decreasing to normal at $17^h 24^m$. The increases were: D, 2′ east; H, 74 gammas; Z, 7 gammas. Sharp peak-voltages occurred in all earth-current lines at the same time. A radio fade-out of intensity three lasted from $17^h 14^m$ to $18^h 04^m$. Strong solar activity was noted during the regular periods of observation just preceding this effect.

October 7—A sudden commencement occurred in all elements at $05^h 21^m$ GMT, October 7. In an interval of three minutes, H increased 36 gammas, D moved westerly nearly 1′, and Z increased 7 gammas.

October 9—From 12^h to 21^h GMT, October 9, the traces showed a series of rapid oscillations of high amplitude.

October 11—From 13^h to 20^h GMT, October 11, the traces showed a series of rapid oscillations of high amplitude.

November 8—From 14^h to 22^h GMT, November 8, a moderate disturbance occurred during which a number of oscillations were recorded.

November 14—Although this was a relatively quiet day, the daily maximum in H was much depressed below the normal from 14^h to 20^h GMT.

November 18—From 12^h to 21^h GMT, November 18, a strong disturbance occurred with a number of oscillations of large amplitude.

November 19—From 11^h to 17^h GMT, November 19, a strong disturbance with a number of oscillations of large amplitude occurred.

November 29—From 11^h to 21^h GMT, November 29, a strong disturbance with a number of oscillations of large amplitude occurred.

December 7—A moderate disturbance occurred with several large fluctuations in *H* from $14^h 30^m$ to $20^h 30^m$ GMT, December 7.

December 18—From 13^h to 21^h GMT, December 18, a moderate disturbance occurred during which *H* decreased to quite a low value of 29410 gammas at $18^h 42^m$.

December 23—A strong disturbance occurred from 11^h to 21^h GMT, December 23. A number of rapid fluctuations in *H* were recorded in this period.

December 24—At $06^h 24^m$ GMT, December 24, an earthquake was recorded on the magnetic trace.

December 31—A strong disturbance occurred from $12^h 30^m$ to 20^h GMT, December 31.

FRANK T. DAVIES, *Observer-in-Charge*

WATHEROO MAGNETIC OBSERVATORY
OCTOBER TO DECEMBER, 1937

(Latitude 30° 19′.1 S., longitude 115° 52′.6 or $7^h 43^m.5$ E. of Gr.)

October 1—See "Note on solar eruption of October 1, 1937" under Letters to Editor in this issue.

October 7-8—A sudden commencement occurred at $05^h 20^m$ GMT, October 7. *D* moved easterly 1′.5, then westerly 3′ abruptly followed by an easterly movement of 3′ during the next three minutes of time. *H* decreased 2 gammas, then increased 15 gammas abruptly followed by a further increase of 15 gammas during the next three minutes. The numerical value of Z decreased 4 gammas, then increased 9 gammas abruptly followed by a decrease of 17 gammas during the next three minutes. The commencement was followed by disturbed conditions which lasted until approximately 17^h, October 8.

November 29-December 1—A sudden commencement occurred at $11^h 42^m$ GMT, November 29. *D* moved easterly 1′.5 then westerly 2′ during two minutes of time. *H* increased 35 gammas in three minutes and then decreased irregularly 55 gammas during the next two hours. The numerical value of *Z* decreased 5 gammas abruptly, then increased 7 gammas during the next two minutes followed by a second decrease of 10 gammas in five minutes, and then increased irregularly 35 gammas during the next two hours. The trace was moderately disturbed until 12^h, December 1.

J. W. GREEN, *Observer-in-Charge*

NOTES

(See also page 76)

7. *American Institute of Mining and Metallurgical Engineers*—The annual meeting of the American Institute of Mining and Metallurgical Engineers was held at the Engineering Societies Building, in New York, February 14-17, 1938. Of particular interest to readers of this JOURNAL was the extensive program on Geophysical Methods of Exploration which covered two whole days. In this program were papers dealing with nearly all aspects of the subject and emanating from a wide area, including Australia, Spain, and Poland. On Tuesday, February 15, a joint session with Mineral Industry Education Division, Petroleum Division and Mining Geology Committee, was held which took the form of a round table of geophysical education dealing particularly with the present status of departments of geophysics and their organization. On the morning of February 17, the papers centered about the general theme of "A perspective of geophysics" among which were two reports on the progress of electrical, geothermal, and radioactive methods, and of magnetometric methods, respectively, during 1937. In the afternoon two papers dealing with geophysical prospecting for oil were given.

8. *International days for special ionospheric measurement during 1938*—The following list of international days during 1938 for special ionospheric measurement have been selected by the Subcommission 1 (Ionospheric Measurements) of Commission II (Radio-Wave Propagation), International Union of Scientific Radio-telegraphy: January 5-6, 19-20; February 2-3, 16-17; March 2-3, 16-17, 30-31; April 13-14, 27-28; May 11-12, 25-26; June 8-9, 22-23; July 6-7, 20-21; August 3-4, 17-18, 31-September 1, 14-15, 28-29; October 12-13, 26-27; November 9-10, 23-24; December 7-8, 21-22.

9. *Selected magnetically disturbed days, 1915 and 1916*—Referring to the note at the end of Table 2—Selected disturbed days, 1895-1905, on page 398 of the December 1937 issue of this JOURNAL, we find that the selected disturbed days for 1915 and 1916 were not published in the "Caractère magnétique de chaque jour" but in the form of a printed letter dated De Bilt, December 1917. As this original letter may not be readily accessible, we are reprinting the selected disturbed days for the two years in question below:

Selected magnetically disturbed days, 1915 and 1916

Month	Year									
	1915					1916				
January	1	5	25	26	27	10	11	12	20	23
February	8	19	20	23	24	8	12	17	18	27
March	7	8	20	21	22	8	9	10	29	30
April	7	8	15	22	26	25	26	27	28	29
May	1	2	16	17	27	21	22	23	30	31
June	12	13	17	18	22	8	18	19	22	23
July	2	6	9	11	27	1	8	9	17	23
August	2	7	26	27	29	6	22	23	26	27
September	22	23	24	28	29	3	4	12	27	30
October	15	19	23	24	25	1	6	7	8	13
November	1	5	6	16	17	4	5	6	12	27
December	6	7	15	16	26	1	2	3	15	27

10. *Grants for magnetic and cosmic-ray research*—Among recent grants for research of the Geological Society of America is that of $1000 to W. F. Prouty, Chapel Hill, North Carolina, for magnetometric study of the origin of the "Carolina bays" of the Atlantic Coastal Plain suspected by some geologists to have been due to a shower of meteors.

The council of the American Association for the Advancement of Science awarded a grant of $300 to Reina Albagli for completion of a study of the allowed cone of cosmic radiation, in particular ofthe so-called penumbra.

11. *Magnetic publications*—The United States Coast and Geodetic Survey announces two additional publications on terrestrial magnetism, which will be ready for distribution within the next three months:

Serial 601—"Magnetic Declination in Arkansas, 1935," contains an isogonic chart of the state of Arkansas for the year 1935. In addition to a general introduction, there are tables of secular changes of declination at the various county-seats, tables of declination measured at magnetic stations, reduced to 1935, and descriptions of all magnetic stations in the State at the present time. Several examples are included illustrating the use of the secular-change tables. This publication supersedes Serial 237 issued for 1923.

Serial 602—"United States Magnetic Tables and Magnetic Charts for 1935" contains charts depicting the distribution and annual change in declination, dip, horizontal intensity, and vertical intensity of the Earth's magnetic field for the United States for 1935. In addition, there are tables giving the results of magnetic observations at practically all magnetic stations in the United States, both observed and reduced to 1935, results at repeat-stations, and tables of secular change of the various magnetic elements at various evenly distributed points throughout the United States. This publication supersedes Serial 453, issued for 1925.

Both of the above publications will be for sale by the Superintendent of Documents, Washington, D. C. Free distribution is limited by law to libraries, educational institutions, and those cooperating in some way with the work of the Coast and Geodetic Survey.

The volume giving the magnetic results for the year 1935 at the Niemegk Observatory is now in press and includes complete hourly values; the hourly values were not published in the volumes for the years 1917 to 1934.

12. *Corrigenda*—In Figure 1, page 44, issue of March 1937, the sign below the arrow under Vertical Intensity read "$-$" instead of "$+$".

In Table 1, page 156, issue of June 1937, the value for hour 18-19 for Sunday read "-27" instead of "$+27$".

In the issue of December 1937 corrections should be made as follows: Page 351, third line, read "$v_{p.}{}^{\sigma}{}_{n}$" instead of "$v_{p.p.}{}^{\sigma}{}_{n}$"; page 362, third paragraph, ninth line, read "in the area" for "at the point"; page 370, fifteenth line, read "where $\triangle Z$ and $\triangle H$ are" for "where Z and H are"; page 391, for entry under November 13, read "133" for "138" and for entry for mean of November, read "115.4" for "115.5"; page 398, second line of last box in Table 2, read "1923" for "1917", insert following the sixth line "The selected disturbed days for the years 1915-22 were published separately and included with the annual summaries—see circular letter, De Bilt, December 1937", add to foot-note "or 'Caractère magnétique de l'anneé 1936,' Appendix, De Bilt, August 1937"; page 414, address and signature following the table should follow table at top of page 415.

13. *Personalia*—M. *Louis Eblé* has been appointed secretary of the French Section of Terrestrial Magnetism and Electricity to succeed Prof. *E. Mathias* who relinquished the post at the close of the Edinburgh Assembly of the International Union of Geodesy and Geophysics after 17 years of service. Prof. Mathias has been appointed to the vice-presidency of the Section in recognition of his valuable services while secretary.

Prof. *Ch. Maurain* has been awarded 15,000 francs under the Fondation Villemot for reasearches in terrestrial magnetism and atmospheric electricity carried out under his direction at the new geophysical observatory at Chambon-la-Forêt, France.

Dr. *W. Filchner* compared his instruments with the magnetic standards of the Niemegk Observatory during February 1938.

Dr. *J. A. Fleming*, Director, Department of Terrestrial Magnetism, Carnegie Institution of Washington, was elected a corresponding member of the Geographical

Society of Finland in connection with the celebration of the Society's fiftieth anniversary in January 1938.

Dr. *E. H. Vestine*, who last year completed a three-year course of study under Prof. S. Chapman at the Imperial College of Science and Technology, London, taking his doctor's degree there in July 1937, joined the staff of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington as Observer on January 27, 1938.

Professor *Charles Lallemand*, former President of the French Academy of Sciences and of the Bureau of Longitudes, Paris, and President of the International Union of Geodesy and Geophysics from its establishment in 1919 until the Lisbon Assembly in 1933, died on his estate near Joinville (Haute-Marne) in his eighty-first year, after four years of illness.

Dr. *George Ellery Hale*, from 1904 to 1923, director of the Mount Wilson Observatory and thereafter its honorary director, died on February 21, 1938, of heart disease, aged 69 years. Aside from his outstanding services to astronomy, Dr. Hale was the discoverer of magnetic fields in sunspots, for which he was awarded, in 1932, the Copley Medal of the Royal Society of London, and gave impetus to correlative studie of solar and terrestrial magnetism. He was also the inventor of the spectrohelioscope now employed in a world-wide net of observatories for the study of eruptions on the solar chromosphere in their relation to geophysical phenomena.

W. M. H. Greaves, chief assistant at the Royal Observatory, Greenwich, has been appointed Astronomer Royal for Scotland and professor of astronomy in the University of Edinburgh. He succeeds Professor R. A. Sampson, who recently retired.

L. V. Berkner, of the staff of the Department of Terrestrial Magnetism, left Washington, February 17, 1938, for London en route to the Watheroo Magnetic Observatory where he will install the automatic multifrequency ionospheric recorder. On the way he will take the opportunity of consulting with workers in ionospheric research in England, Australia, and New Zealand. He will be absent from Washington during the present year and plans to visit the Mount Wilson Observatory on his return next spring.

Rear. Admiral *Raymond Stanton Patton*, Director of the United States Coast and Geodetic Survey since 1929, died at his home in Washington, D. C., November 25, 1937, at the age of 54 years.

The Right Hon. Viscount Swinton, Secretary of State for Air has appointed Mr. *N. K. Johnson* to be Director of the Meteorological Office, London, upon the retirement of Sir *George C. Simpson* which will take place in September, 1938.

14. *Meeting of German Geophysical Society, 1938*—The German Geophysical Society will hold its biennial meeting October 20 to 22, 1938, at Jena. The program will include terrestrial magnetism and electricty, ionospheric studies, and applied geophysics. Communications on these subjects are invited and those who desire to submit papers should notify Dr. *J. Bartels*, Geophysikalisches Institut, Telegrafenberg, Potsdam, by September 1, 1938.

LIST OF RECENT PUBLICATIONS

By H. D. Harradon

A—Terrestrial and Cosmical Magnetism

Apia Observatory. Annual report for 1934. Issued under the authority of the Hon. D. G. Sullivan, Minister of Scientific and Industrial Research. Wellington, G. H. Loney, Govt. Printer, 1937 (121). 25 cm.

Burgaud, M., et Fr. Lou. Carte magnétique de Chine. Shanghai, Imprimerie de la Mission Catholique, 1937 (74 avec cartes). 31 cm. [Observatoire de Zi-ka-wei. Etudes sur le magnétisme terrestre, Etude 40. Fascicule X.]

Chapman, S. Radio fade-outs and the associated magnetic variations. Terr. Mag., Washington, D. C., v. 42, No. 4, 1937 (417-419).

Dijk, G. van. The magnetic character of the year 1936 and the numerical magnetic character of days 1936. Terr. Mag., Washington, D. C., v. 42, No. 4, 1937 (395-396).

Internationally selected magnetically quiet days and disturbed days 1895-1905. Terr. Mag., Washington, D. C., v. 42, No. 4, 1937 (397-398).

Egedal, J. The determination of the magnetic inclination with an earth-inductor. Terr. Mag., Washington, D. C., v. 42, No. 4, 1937 (367-370).

Errulat, F. Die erdmagnetische Deklination in Ostpreussen für 1935.0. Ann. Hydrogr., Berlin, Jahrg. 65, Heft 11, 1937 (519-521).

Fanselau, G. Ueber eine photographische Ableseeinrichtung am Doppelkompass. Zs. Geophysik, Jahrg. 13, Heft 6, 1937 (235-238).

Filchner, W. Kartenwerk der erdmagnetischen Forschungs-Expedition nach Zentral-Asien 1926-28. Zweiter Teil: Tibet II. Petermanns geogr. Mitt., Gotha, Ergänzungsheft No. 231, 1937 (235 mit 73 Skizzen und 3 Tafeln). 28 cm.

Gallo, J. Memoria de la expedición magnética a Mérida y Campeche. Mexico, Imprenta Reveles, 1937, 27 pp. 23 cm. [Instituto Panamericano de Geografía e Historia, Pub. No. 29.]

Gunn, R. An improved inductor-compass. Terr. Mag., Washington, D. C., v. 42, No. 4, 1937 (363-366).

Heck, N. H. The magnetic survey of the United States. Military Eng., Washington, D. C., v. 30, No. 169, 1938 (13-17).

Kirby, S. S. Remarks on S. Chapman's note on radio fade-outs and the associated magnetic disturbances. Terr. Mag., Washington, D. C., v. 42, No. 4, 1937 (420).

Ksara, Observatoire de. Annales de l'Observatoire de Ksara (Liban) dirigé par les PP. de la Compagnie de Jésus. Observations (Section Magnétique). Année 1936. (61 avec 3 feuilles de reproductions des enregistrements de perturbations magnétiques.) 32 cm.

London, Admiralty. Curves of equal magnetic variation, 1937. Reduced to that epoch from observations by the officers of His Majesty's Navy and from surveys carried out by colonial and foreign governments and by the Carnegie Institution of Washington. Compiled at the Royal Observatory, Greenwich. London, Admiralty, Sept. 24, 1937, 98 x 45 cm. [At the top there are three small charts showing approximate curves of equal magnetic variation in the north and south polar regions and of approximate annual change of magnetic variation for epoch 1937 in minutes of arc.]

London, Meteorological Office. Annual report of the Director of the Meteorological Office presented by the Meteorological Committee to the Air Council for the year ended March 31, 1937. London, H. M. Stationery Office, 1936 (56). 24 cm. [Contains brief reports on Kew, Eskdalemuir, Aberdeen, Lerwick, and Valentia observatories.]

McNish, A. G. Terrestrial magnetic variations and the ionosphere. J. Applied Phys., Lancaster, Pa., v. 8, No. 11, 1937 (718-731).

Remarks on Dr. Chapman's note on radio fade-outs and the associated magnetic disturbances. Terr. Mag., Washington, D. C., v. 42, No. 4, 1937 (419).

Magnetic Research Work in Tankers. Magnetic research work in tankers. By a Dutch reader. Naut. Mag., Glasgow, v. 138, 1937 (302-304).

Mauritius, Royal Alfred Observatory. Annual report of the Royal Alfred Observatory for the year 1936. Port Louis, R. W. Brooks, Govt. Printer, 1937, 8 pp. 24 cm. [Contains brief report of magnetic work and gives the mean values of the magnetic elements for 1936.]

Results of magnetical and meteorological observations for the months of March to October 1936 (new series, v. 22, pts. 3-10). Port Louis, R. W. Brooks, Govt. Printer, 1937 (33-160).

Meier, P. Ergebnisse der magnetischen Beobachtungen im Jahre 1932 in Wilhelmshavn. Von Paul Meier. Hamburg, Aus d. Arch. Seewarte, Bd. 57, Nr. 6, 1937 (39 mit 7 Zahlentafeln und 2 Figurentafeln).

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Minnaert, M. On the possibility of detecting the general magnetic field of a star. Observatory. London, v. 60, No. 762, 1937 (292-294).

Ogg, A. Progress of magnetic survey in the Union of South Africa. Terr. Mag., Washington, D. C., v. 42, No. 4, 1937 (408).

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Pushkov, N. V., N. S. Brunkovskaja, and N. V. Abramova. Comparison of the auroral and magnetic activity according to observations at Calm Bay in 1932-1933. Met. i Hidrol., Moskva, No. 6, 1937 (75-83). [Russian text.]

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Sandoval, R. O. Estudio de una onda magnética. Tacubaya, Observatorio Astronómico Nacional, Bol. Núm. 16, 1937 (9-18).

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Stonyhurst College Observatory. Results of geophysical and solar observations, 1936. With report and notes of the Director, Rev. J. P. Rowland. Blackburn, Thomas Briggs, Ltd., 1937 (xx+40). 18 cm.

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Visser, S. W. A connection between deep-focus earthquakes and anomalies of terrestrial magnetism and gravity. Terr. Mag., Washington, D. C., v. 42, No. 4, 1937 (361-362).

Wasserfall, K. F. Some of the most characteristic features in the variation of magnetic elements. (Based upon the material collected at Dombås Observatory.) Pub. Inst. Kosmisk Fys., Bergen, Nr. 10, 1937 (24 with 8 figs.).

Wien, Zentralanstalt für Meteorologie und Geodynamik. Jahrbücher der Zentralanstalt für Meteorologie und Geodynamik. Amtliche Veröffentlichung. Jahrgang 1932, Neue Folge, LXIX. Band. Der ganzen Reihe LXXVII. Band. (Pub. No. 144.) Wien, In Kommission bei Gerold und Komp., 1936 (xx+A 30+B 39+C 10+E 1). 32 cm. [Contains results of magnetic observations at station Wien-Auhof in the year 1932.]

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B—Terrestrial and Cosmical Electricity

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BROOKS, C. F. Auroras of September 4 and 10, 1937. Terr. Mag., Washington, D. C., v. 42, No. 4, 1937 (416).

CLAY, J., AND M. A. VAN TIJN. Artificial radioactivity produced by cosmic rays. Physica, The Hague, v. 4, No. 9, 1937 (909-912).

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LUNAR DIURNAL VARIATION IN EARTH-CURRENTS AT HUANCAYO AND TUCSON

BY W. J. ROONEY

Abstract—The lunar diurnal variation in earth-current flow at Huancayo and Tucson has been determined from the records for the year 1932, near the sunspot-minimum. Using the method employed by Chapman for the magnetic elements, a definite lunar diurnal variation of markedly double period is found in both components of the potential-gradient at both stations. Harmonic analyses of the mean curves show that at Huancayo the amplitude of the second harmonic is about one-sixth that of the solar diurnal variation for the same year, while the amplitudes of the first, third, and fourth harmonics are negligibly small. At Tucson the amplitude of the second harmonic is about one-fifth that of the solar diurnal variation for the northward component which is the principal component at that station.

The manner in which the lunar diurnal variation changes with the phase of the Moon was also examined. For both components at Huancayo, curves constructed for the four main phases of the Moon show a marked increase in activity during daylight hours and a corresponding diminution during the night so that the individual curves are no longer semi-diurnal. For Tucson the curves for the individual phases of the Moon, as determined from this single year's record are too irregular to show the changes definitely, but do indicate that they are less pronounced at this higher-latitude station. As a check on this point the lunar diurnal variation at Tucson was redetermined by the method applied by Egedal to the data from Ebro. In this method the lunar diurnal variation is obtained from the records for the individual hours of the solar day. Using the hours from 12 to 24 the lunar diurnal variation found is in good agreement with that obtained by the usual method. Comparing the lunar diurnal variation obtained separately by this method during daylight, 12^h to 18^h, with that obtained during the night, 18^h to 24^h, there is found only a slight decrease in amplitude from day to night and very little change in phase. These results are in agreement with those obtained by the first method and also with the revised conclusions reached by Egedal from his studies of the Ebro records.

Lunar diurnal variation (L) in the Earth's magnetic field is quite definitely established. It has been discussed by Chapman, Bartels, and others and its general features are well known. To sum these up briefly, L, for any element or any station, is semi-diurnal, the curves approaching closely to a double sine-wave. There is some difference in phase and amplitude for different stations but the mean curves obtained at all stations are very much alike. When L is determined for different phases of the Moon, a decided difference is found between the hours of daylight and those of darkness. The amplitude of the variation is increased markedly during daylight and correspondingly decreased during the night so that the curves are no longer semi-diurnal in character.

Because of the close connection between earth-currents and terrestrial magnetism it is interesting to see how much, if any, lunar diurnal variation is detectible in the results of earth-current measurements. And since, as has been pointed out frequently, earth-current studies must be largely restricted to a study of variations, the interest in lunar diurnal variation should be more pronounced in their case. However, until recently the existence of a lunar diurnal variation in earth-current flow has merely been inferred from that found in the Earth's magnetic field and very little has been done in the way of evaluating it. During the past year Egedal[1] published a summary of the results of his analyses of a single year's records from Ebro showing the lunar diurnal variation at that station, and Rougerie[2] reported on that determined from the records obtained at the installation at Parc St Maur at Paris during the last part of the last century. Aside from these two papers practically nothing has been published on the subject.

The present report covers some preliminary work on the determination of lunar diurnal variation in earth-currents at Huancayo and Tucson, directed primarily toward finding out just what is the best method for determining $L_{E\text{-}C}$, and the amount of data necessary for a satisfactory evaluation of it. The records treated are those for the year 1932. This year was close to the last sunspot-minimum and consequently was a period of low magnetic and earth-current activity and of minimum disturbance.

The first step taken in order to determine whether the lunar diurnal variation is of sufficient magnitude to be important consisted of an examination of the usual solar diurnal-variation curves for lunar effects.

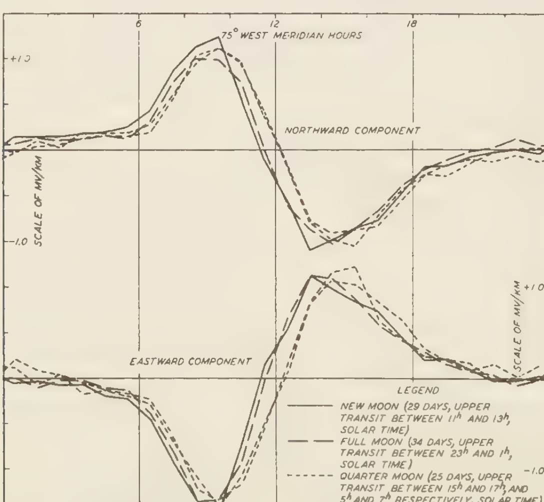

FIG. 1—SOLAR DIURNAL-VARIATION IN EARTH-CURRENTS AT PRINCIPAL PHASES OF MOON DURING YEAR, HUANCAYO MAGNETIC OBSERVATORY, 1932

[1]J. Egedal, Terr. Mag., **42**, 179-181 (1937) and **43**, 89 (1938).

[2]P. Rougerie, C.-R. Acad. sci., Paris, **205**, 1252-1253 (1937).

Figure 1 shows the solar diurnal variation at Huancayo at the four main phases of the Moon for the year 1932. The solid curve is for New Moon. It was constructed from the records from 29 days when the upper transit of the Moon occurred between 11^h and 13^h solar time. The broken curve is for Full Moon, from 34 days when the upper transit fell between 23^h and 1^h; the two dotted curves represent conditions at Quarter Moon, from approximately the same number of days when the upper transit occurred between 15^h and 17^h, and between 5^h and 7^h, solar time, respectively. The solar diurnal-variation curve at Huancayo is primarily one of single period, yet it is quite definitely modified by the semi-diurnal lunar variation, the modification appearing chiefly as a shift in the times of the daily maximum and minimum. Although only a comparatively few days' records are included in the curves in Figure 1, the differences are quite as distinct as those found between calm and disturbed days over a period of several years. Harmonic analyses were made of these data and the harmonic dials for the first four components all indicate a rotary motion of the solar vector such as should accompany the superposition of a lunar variation upon it.

A similar examination of the solar diurnal variation at Tucson, using practically the same days, was also made. The curves obtained for this station were somewhat less regular, partly because of the greater amount of disturbance at the higher latitude, but they show a pronounced lunar effect. This is readily apparent when the data are presented in the form of hodograms as shown in Figure 2.

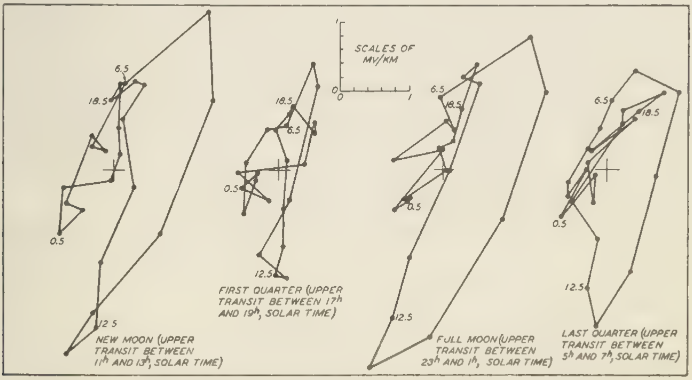

FIG. 2—SOLAR DIURNAL-VARIATION IN EARTH-CURRENTS AT GIVEN PHASES OF MOON, TUCSON, 1932 (NUMBERS ON CURVES ARE 105° WEST MERIDIAN HOURS)

Because of the large seasonal changes in earth-current flow at Tucson[3] it seemed possible that some of the differences shown in Figure 2 might be due to irregular distribution of the days throughout the seasons, the records not being complete enough to permit an exact distribution. Harmonic analyses of the mean records for the 107 days used indicated that they are highly representative, practically no difference being noted either in phase- or amplitude-coefficients between these days and all days of the year. As a further check on this point another set of hodo-

[3]W. J. Rooney, Terr. Mag., 40, 183-192 (1935).

grams was constructed using only the period from April to October, during which the form of the solar hodogram does not change materially. This comparison, which omitted the comparatively inactive months of November, December, and February, and the anomalous ones, January and March, showed the same type of difference at the several phases of the Moon as that seen in Figure 2.

It might be mentioned here that neither in the examination of the solar diurnal variation nor in the determination of the lunar variation was there any selection of days with reference to calmness or disturbance. In constructing the mean curves all days for which the record was complete were used, and the only selection made in testing the results at different phases of the Moon was the phase of the Moon itself. Moreover, it so happens that the average character-figure for each of the groups of days corresponding to a given phase of Moon was just about the same and also just about the same as that for the year as a whole. Hence while disturbances must have some effect when the days included are so few, they can scarcely be held responsible for the greater part of the differences found in the curves.

Since a definite lunar effect was thus shown in the solar diurnal-variation records, the evaluation of the lunar diurnal variation itself was next in order. There are two methods by which it can be determined. The more usual one is that used by Chapman and others on the magnetic records. In it the solar variation is removed from the hourly data for each component by subtracting from each hourly value during a given period (usually, and in this case, one month) the mean departure for that period at that solar hour from the monthly mean. The revised hourly values are then rearranged in rows each containing 24 or 25 successive values, the initial value in each row being that for an hour nearest to a given lunar transit. The lunar diurnal variation may then be determined by averaging up the columns and subtracting each from the mean of all just as the solar diurnal variation is obtained from the original records. Adequate evaluation depends merely on having enough data so that variations due to disturbances will average out—as they will eventually since they are not related to lunar time.

Mean lunar diurnal-variation curves for the year 1932, determined

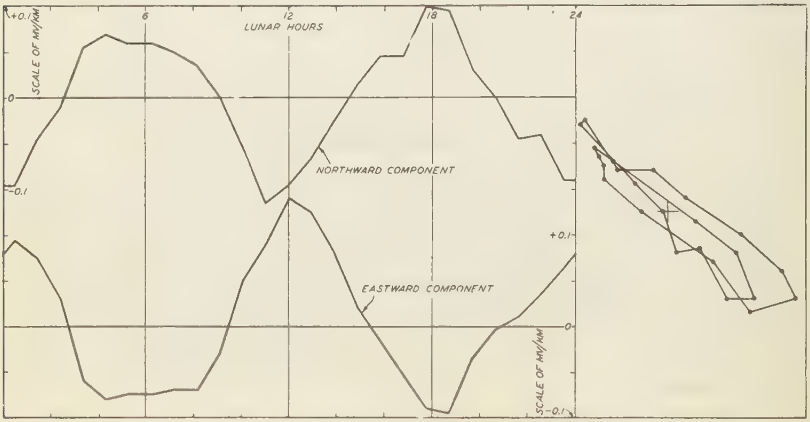

FIG. 3—MEAN LUNAR DIURNAL-VARIATION IN EARTH-CURRENTS, HUANCAYO, 1932

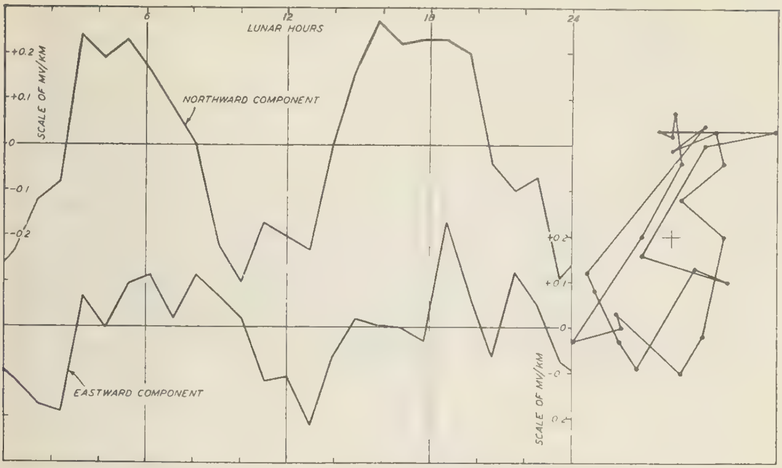

FIG. 4—MEAN LUNAR DIURNAL-VARIATION IN EARTH-CURRENTS, TUCSON, 1932

in this way are shown for the northward and eastward components of earth-current potential-gradient at Huancayo and Tucson in Figures 3 and 4. All complete days were used in the case of both observatories, the number of days included ranging from 324 to 328 for the individual curves. Harmonic analyses of the data, as given in Table 1, bring out even more clearly than do the curves the simple semi-diurnal character of the variation. The magnitude of the lunar diurnal variation differs by a factor of two or more at Huancayo and Tucson, a result which is not unexpected since the solar diurnal-variation curves for these two stations differ markedly both in form and magnitude. Reference to

TABLE 1—*Fourier analyses of earth-current potential-gradient records at Huancayo and Tucson, showing lunar diurnal variation in comparison with solar diurnal variation, 1932*

Diurnal variation	Amplitudes and phase	Huancayo		Tucson	
		Northward component	Eastward component	Northward component	Eastward component
Lunar	c_1 in mv/km	0.01	0.02	0.05	0.01
	c_2 in mv/km	0.08	0.09	0.23	0.11
	c_3 in mv/km	0	0.01	0.03	0.04
	c_4 in mv/km	0.01	0.01	0.04	0.03
	ϕ_2 in °	280	83	289	242
Solar	c_1 in mv/km	0.55	0.64	0.27	0.31
	c_2 in mv/km	0.47	0.55	1.28	0.35
	c_3 in mv/km	0.24	0.29	0.68	0.27
	c_4 in mv/km	0.07	0.09	0.24	0.13
	ϕ_2 in °	176	358	263	228
Ratio (c_2 lunar/c_2 solar)		1/6	1/6	1/5	1/3

For Ebro (1910) Egedal gives c_2 lunar as 1.95 mv/km; this is about one-fifth of the value for c_2 solar for that station as determined by Bauer and Ennis.

Table 1 will show, however, that the ratio of the amplitude of the second or principal harmonic of the lunar variation to that of the solar variation is very nearly the same in both cases.

The hodograms, or vector-diagrams, in Figures 3 and 4 do depart considerably from the ideal double loops which would be given by purely double sine-curves. The rather sharp breaks in the Tucson hodograms are typical of disturbance-effects and are almost certainly due to the fact that such effects have not been averaged out. The inclusion of more data can be expected to result in a much smoother graph. Both hodograms show a restriction in the direction of current-flow, most pronounced at Huancayo where the greater part of the flow occurs along a line nearly northwest to southeast. An exactly similar restriction is a feature of the hodograms representing solar diurnal variation at this station. This strengthens the conclusion that it is due at least in part to topographical conditions. There is less restriction of

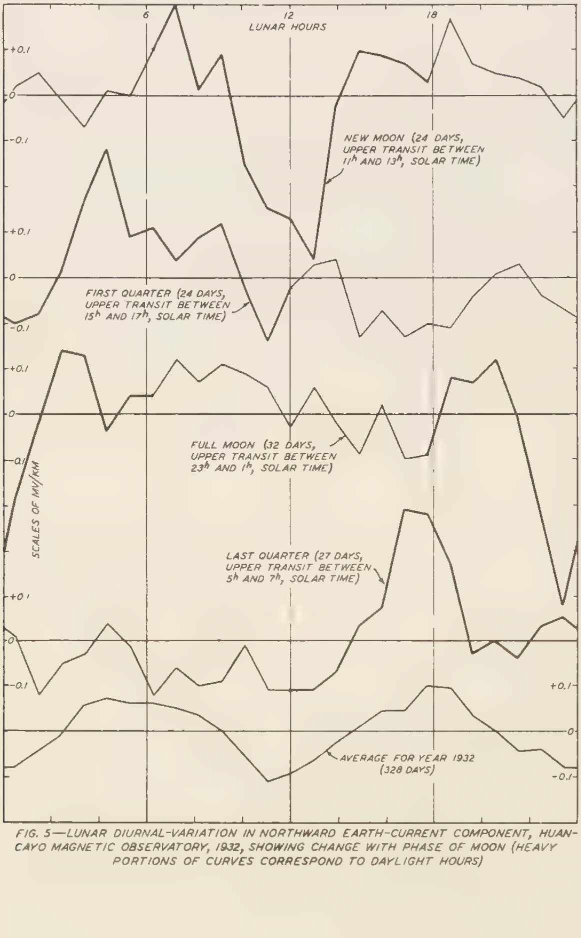

FIG. 5—LUNAR DIURNAL-VARIATION IN NORTHWARD EARTH-CURRENT COMPONENT, HUANCAYO MAGNETIC OBSERVATORY, 1932, SHOWING CHANGE WITH PHASE OF MOON (HEAVY PORTIONS OF CURVES CORRESPOND TO DAYLIGHT HOURS)

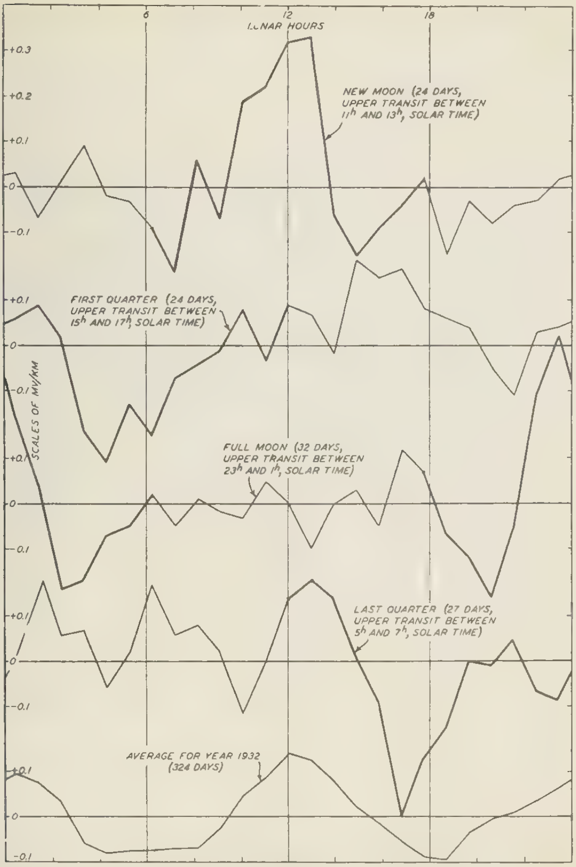

FIG. 6—LUNAR DIURNAL-VARIATION IN EASTWARD EARTH-CURRENT COMPONENT, HUANCAYO MAGNETIC OBSERVATORY, 1932, SHOWING CHANGE WITH PHASE OF MOON (HEAVY PORTIONS OF CURVES CORRESPOND TO DAYLIGHT HOURS)

the direction of flow at Tucson, but the hodogram does indicate the same preference for flow along a line somewhat east of north (approximately along the magnetic meridian), which is apparent in the solar hodograms for this station during the greater part of the year.

A determination of the lunar diurnal variation at various phases of the Moon was next attempted. The results for Huancayo are shown in Figures 5 and 6. Starting at the top of Figure 5, we have the lunar diurnal variation of the northward component at New Moon, a curve constructed from the records of 24 days when the upper transit occurred between 11^{h} and 13^{h} solar time. Following in order are, First Quarter (24 days—upper transit between 15^{h} and 17^{h}), Full Moon (32 days—upper transit between 23^{h} and 1^{h}), and Last Quarter (27 days—upper transit between 5^{h} and 7^{h}). The bottom curve is the mean curve for

the year (328 days). Figure 6 gives a similar set of curves for the eastward component. The heavy portions of the curves represent hours of daylight.

The solar diurnal variation having been eliminated in the process of determining the lunar variation, the curves in Figures 5 and 6 are unaffected by solar variations except in so far as variability in the solar diurnal variation from day to day may result in some residue of it existing in the data. Hence the curves represent mostly changes in the lunar diurnal variation itself. The chief feature of the curves is the markedly greater activity recorded during the hours of daylight. Just as has been found in magnetic studies, the general features of the graphs for the individual phases of the Moon are such as would be obtained from the mean graph by increasing the range during the day and decreasing it at night. No smoothing process has been applied to the data and the curves are admittedly rough, but the really remarkable feature of them is that such definite evidence of the changes which occur in the lunar diurnal variation can be shown from so few data.

The same treatment of the single year's records from Tucson, applied to the northerly component only, did not give such satisfactory results. The curves constructed for the individual phases of the Moon were too irregular to show with any clearness how the lunar diurnal variation changes with the phase of the Moon. The greater influence of disturbances as one moves away from the equator may be considered chiefly responsible, although the changes which take place in the solar variations throughout the year at this station may have some effect also. It appears that a number of years' data will have to be included to get a fair picture of such changes at Tucson.

Results of harmonic analyses of the lunar diurnal variation at different phases of the Moon are shown for both stations in Table 2. Reference to this Table shows that the curves for the individual phases of the Moon at Tucson are still predominately of double period, the amplitude-

TABLE 2—*Fourier analyses of lunar diurnal variation in earth-current potential-gradient for separate phases of the Moon at Huancayo and Tucson, 1932*

Observatory and component	Amplitudes and phase	Mean	New Moon	First Quarter	Full Moon	Last Quarter
Huancayo, northward	c_1 in mv/km	0.01	0.07	0.09	0.08	0.09
	c_2 in mv/km	0.08	0.12	0.03	0.06	0.07
	c_3 in mv/km	0	0.08	0.06	0.08	0.05
	c_4 in mv/km	0.01	0.05	0.02	0.08	0.06
	ϕ_2 in °	280	264	277	254	289
Huancayo, eastward	c_1 in mv/km	0.02	0.07	0.11	0.03	0.08
	c_2 in mv/km	0.09	0.10	0.05	0.06	0.07
	c_3 in mv/km	0.01	0.09	0.08	0.10	0.07
	c_4 in mv/km	0.01	0.05	0.02	0.10	0.09
	ϕ_2 in °	83	96	68	101	77
Tucson, northerly	c_1 in mv/km	0.05	0.12	0.11	0.05	0.05
	c_2 in mv/km	0.26	0.40	0.30	0.29	0.43
	c_3 in mv/km	0.03	0.14	0.28	0.20	0.10
	c_4 in mv/km	0.02	0.09	0.20	0.08	0.19
	ϕ_2 in °	286	292	283	296	293

coefficients for the second harmonic being consistently larger than those for the first, third, or fourth. At Huancayo, on the other hand, the first and third harmonics of the individual curves are at least as great as the second. Hence the Tucson data, crude as they are, do show one thing, namely, that the changes in the lunar diurnal variation with phase of the Moon are less pronounced there than they are at Huancayo. This would indicate that the lunar variation at higher latitudes is less subject to changes due to variations in the ionization of the *L*-layer, wherever it may be, than it is near the equator.

An alternate method may be used to determine lunar diurnal variation, similar to that employed by Egedal in his study of the Ebro records. It simply consists of taking the usual monthly tabulation-sheet for a given component, starting at the value for an hour which coincides with a lunar transit. If we proceed up the sheet from this point, each value is theoretically unaffected by solar diurnal variation since it comes in the same solar hour, but each represents a progressively later interval in the lunar day until we come to a value which coincides with the same lunar transit from which we started. It is consequently merely necessary to rearrange the values in rows as before without subtracting out anything. Instead of 24 or 25 values in each row, we have 28, 29, or occasionally 30, the lunar diurnal variation being obtained as before by averaging the columns and subtracting from each the mean of all. This method eliminates one operation—the subtraction of the solar variation—but requires rather more complete records. Using the usual method incomplete daily records can be ignored, but in this second method it is necessary to interpolate values or else drop a lunar day for every missing solar hour's record. As far as earth-currents are concerned it is open to the

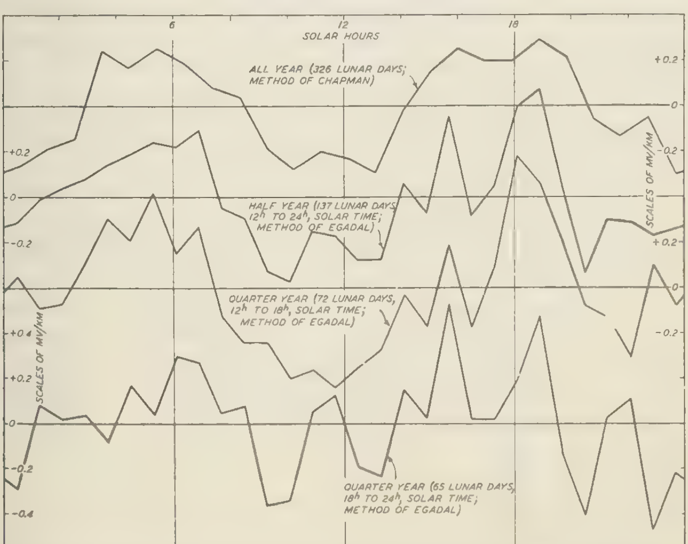

FIG. 7—LUNAR DIURNAL-VARIATION IN NORTHERLY COMPONENT OF EARTH-CURRENTS, TUCSON, 1932 (AS DETERMINED BY METHODS OF CHAPMAN AND EGADAL)

objection that the results are far more likely to be influenced by variations in the contact-potentials at the electrodes. If enough data are used this type of variation should average out just like that due to disturbances, but for periods of a month or even a year, rather serious errors might be introduced into the results from contact-potential variations.

The longer the lines used to measure earth-currents the less strength there is to this objection and the method affords a means to check the results obtained at a station like Tucson. Figure 7 shows the lunar diurnal variation in the northerly component at Tucson as determined by the two methods. The top curve is the all-year curve obtained by the first method. It is very like the true northward curve seen in Figure 4. The second curve was obtained by the second method for half the year. "Half-year" in this case does not mean six months. In order to average out seasonal effects and at the same time have a sufficient number of lunar days in each group when the year was still further subdivided, the year was split up, as we might say, vertically instead of horizontally. Thus the second curve was obtained by using the records for the solar hours 12 to 24 for all days of the year. The curve so constructed is somewhat more irregular than the top curve but not more so than should be expected since it includes only 137 lunar days as against 326 for the all-year curve. The two lower curves were also obtained by the second method for quarter-year periods—the split being again made vertically. The third curve includes the daylight hours, 12 to 18, and represents a total of 72 lunar days, while the fourth one includes the dark hours, 18 to 24, a total of 65 lunar days. Harmonic analyses of these curves gave results as shown in Table 3.

Curves of the actual lunar diurnal variation at different phases of the Moon, like those shown for Huancayo in Figures 5 and 6, cannot be obtained by the second method. There can be determined, however, a pseudo-lunar diurnal variation, for day, or for night, or for any given solar hour of the day, which will represent what the lunar diurnal variation would be if the conditions affecting the ionization of the *L*-layer were more or less constant at their average value for the part of the solar day considered. Such pseudo-lunar diurnal variation, which, strictly speaking is just as real as the mean lunar diurnal variation itself, should

TABLE 3—*Fourier analyses of lunar diurnal variation in earth-current potential-gradient at Tucson as determined by methods of Chapman and Egedal, for entire year and for selected solar hours for records from northerly line only; direction 19° 33′ east of north*

Amplitudes and phase	After Chapman	After Egedal		
	Entire year 326 lunar days	Day and night, 137 lunar days solar hours 12 to 24	Day only 72 lunar days solar hours 12 to 18	Night only, 65 lunar days solar hours 18 to 24
c_1 in mv/km	0.05	0.06	0.15	0.04
c_2 in mv/km	0.26	0.23	0.27	0.19
c_3 in mv/km	0.03	0.01	0.02	0.03
c_4 in mv/km	0.02	0.08	0.09	0.04
ϕ_2 in °	286	299	292	305

result in curves and as far as it has been determined does result in curves—of double period like the mean curve. The two lower curves in Figure 7 are of this character. Both the curves and the analyses of them show some diminution in amplitude during the hours of darkness but considerably less than would be expected on the basis of the curves obtained by the other method at Huancayo. However, since the first method also, when applied to Tucson, indicated that the lunar diurnal variation there changes less with phase of the Moon than does that at Huancayo, the results of the two methods are in substantial agreement.

With the exception of a curve showing the mean lunar diurnal variation for the year Egedal's results for Ebro are all given in terms of the amplitude-coefficient and phase-angle of the second harmonic. They may be briefly summarized as follows:

TABLE 4—*Lunar diurnal variation at Ebro for year 1910*

Period	c_2	ϕ_2
	mv/km	°
All-year curve, both day and night	1.95	33
Daylight hours, 6 to 19	2.2	44
Night hours, 20 to 5	1.8	15

Since Ebro and Tucson are both middle-latitude stations, the Ebro results should be expected to resemble those at Tucson rather than at Huancayo. In his original paper[1] Egedal reported considerable differences both in phase- and amplitude-coefficients for the lunar variations during the day and night but recently revised his results to those shown here. These, it will be noted, are quite similar to the Tucson results in this respect. Referring to the mean lunar diurnal variation Egedal states that its amplitude is about one-tenth that of the solar diurnal variation. His value of 1.95 mv/km is, however, about one-fifth that of the coefficient c_2 of the solar diurnal variation at Ebro as determined by Bauer and Ennis, so that a comparison of the lunar and solar variations on the basis shown in Table 1 for Huancayo and Tucson gives very similar results as to their comparative magnitudes.

Rougerie[2] recently published a brief article on the lunar diurnal variation in earth-currents at the Parc St. Maur station near Paris. He finds its amplitude to be equal to one-quarter the total solar diurnal variation. It is possible that he refers to the amplitude of the second harmonic of the solar variation instead of to the total variation. On this basis the results are quite comparable to those determined here.

To sum up, it appears that the general features of the lunar diurnal variation in earth-current flow can be determined from a comparatively short series of records. Two or three years should be quite adequate. The monthly mean $L_{E\text{-}C}$ is semi-diurnal and its amplitude is not more than one magnitude smaller than that of the solar diurnal variation. As is the case with the magnetic elements, the form of the mean curves seems to be independent of latitude, in which respect they differ markedly from the curves of solar diurnal variation. At an equatorial station the variation of L with phase of the Moon is obtained with fair accuracy from a single year's record and is similar to that found in the magnetic

elements. For higher-latitude stations additional data will be required to show variations of this kind. There is apparently less difference between conditions during day and night affecting lunar diurnal variation in middle latitudes than at the equator, which indicates that the effects of variations in the ionization of the L-layer are most pronounced near the equator. To determine such features as the annual variation in L, its relation to the sunspot-cycle, variation with magnetic and earth-current activity, and any day-by-day variation on quiet days, considerably longer periods of recording must be considered.

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NATURAL RESIDUAL MAGNETISM OF ERUPTIVE ROCKS

By J. G. Koenigsberger

Part I—*General*

The study of the magnetic behavior of rocks under the influence of the Earth's magnetic field and of time, and the study of the history of terrestrial magnetism by aid of the rocks and minerals is facilitated by a knowledge of some new facts connected with physics, physical chemistry, mineralogy, and petrography. As the literature is scattered through many periodicals in various languages, the facts, which are not generally known, are summarized here. Some of these appear of interest in connection with the general theory of ferromagnetism.

§ 1. Among the carriers of ferromagnetism in eruptive and sedimentary rocks is magnetite [see 1848 and 1896*a* under "Literature" at end of paper, and 1913*a* for exact study of magnetic qualities]. This is the principal and often the only ferromagnetic substance, with a grain-size of about two mm down to one μ and less, often isometric, but also occurring in long chains showing less demagnetizing effects or with TiO_2 in half-open shells and skeletons of crystal structure [1924*a*, 1926*a*, 1932*g*]. The chemical composition is Fe_3O_4 (cell-edge $a_0 = 8.38$ Å) but mostly with FeO (iozite) or Fe_2O_3 (maghemite) in excess [1919*b*, 1929*a*] and with additions of TiO_2, interposed in the space-lattice; these remain there until changes are brought about, mostly by unmixing, through heating under conditions in the laboratory [see 1932*a* where further literature is quoted, and 1935*f*, 1936*a*]. An excess of FeO associated with TiO_2 in magnetite (titanoiozite) is often found in basalts [1904*a*, 1932*a*, 1935*g*]; an excess of Fe_2O_3 associated with TiO_2 often gives rise to maghemite with cell-edge of 8.32 Å [1925*e*, 1925*d*, 1926*b*, 1928*a* and *b*, 1932*b*, 1931*e*, 1934*f*] or titanomaghemite $(FeTi)_2O_3$ in gabbro norite, etc. [1933*i*].

Other ferromagnetic substances are pyrrhotite [1905*b*, 1928*g*, 1931*e*, 1934*c*, 1935*b* and *h*] in mass mostly much less than one-third of magnetite; the natural remanence, although about the same as for magnetite because of lower percentage, is generally much less than one-half, and the susceptibility for weak fields in rocks is generally less than one-fourth that of magnetite.

Ilmenite ($FeO—TiO_2$) [1904*b*, 1925*d*, 1926*b*, 1932*e*, 1934*d*] with an excess of FeO or of Fe_2O_3 in the rhombohedral space-lattice, has magnetic effects in rocks generally less than one-tenth those due to magnetite, because of smaller percentage and weaker J_r and K.

Hematite (oligiste, $\alpha - Fe_2O_3 = FeO + FeO_2$) [1897*a*, 1907*b*, 1916*a*, 1930*a*, 1935*a*, 1937*a*] with an excess of TiO_2 in the space-lattice, has a magnetic effect in rocks generally less than one-twentieth of those due to magnetite.

§ 2. The susceptibility K_0* in the field H of 0.45 oersted per cc (or χ per gram) and the natural or fossil residual remanence, J_{rn} per cc of eruptive rocks, influence the Earth's magnetic field causing anomalies [see literature given in 1935*g*, p. 242]. Therefore, for applied geophysics as well as for the studies mentioned above, a characteristic parameter is $(J_{rn}, K_0 H) = Q_n$ (the total value of H being about 0.45

*The contribution to K_0 by paramagnetic minerals (biotite, hornblende, epidote, augite, olivine, etc.) in rocks should be deducted—for granite, syenite, quartz, porphyry about 1 to 2×10^{-5}; for diorite, porphyry, etc., 2 to 3×10^{-5}; for diabase, basalt, gabbro norite 3 to 6×10^{-5}. On heating these minerals give some magnetite thus increasing K_0 [1929*c*]

oersted). It is known that J_{rn} can have very large or very small values and that the direction of J_{rn} can form any angle with the present direction of H. These facts have aroused the interest of scientists and have led to conclusions concerning the direction of the Earth's field at the time when J_{rn} was acquired, as well as regarding the whole effect of effusive and intrusive rocks [1912*c*, 1800, 1846, 1848, 1852, 1853*a*, 1890*a*, *b*, *c*, 1898, 1895*a*, 1901, 1904*c*, 1905*a*, 1913, 1925*b* and *c*, 1926*c*, 1927*a* and *b*, 1928*e*, 1929*a* and *g*, 1931*c*, 1932*c*, *d*, *h*, and *i*, 1933*d*, 1935*k*]. For bricks and baked-clay vessels there are many references [1691, 1863, 1862, 1890*a*, 1894, 1895*b*, 1896*b*, 1897*b*, 1899, 1902*a*, 1906*a*, 1907*c*, 1909*b*, 1910, 1914, 1918*a*, 1932*d'*, 1933*c*].

§ 3. The fact that eruptive rocks and baked materials have a value of J_{rn} much larger than can be acquired in the present terrestrial-magnetic field at 20°C has been known since 1800 [see references above] and this was attributed to the previous high temperature of the materials as proved experimentally [1895*a*, 1904*a*, 1909*a*, 1912*b*, 1919*a*, 1925*c*, 1927*a*, *b*, 1928*b*, 1930*i*, 1935*k*]. It was later shown that the cooling of ferromagnetic materials in the Earth's field from the Curie point (at temperature T_c in °C) to a lower temperature gives the effect [1930*c* and *d*, 1932*d* and *d'*, 1933*b*, *c*, *g*, and *g'*, 1935*g*], which depends on the change with temperature of the coercive force H_c (1933*g* and *g'*) and on the demagnetizing force H_d near T_c.

The full apparent remanence acquired by cooling in a given field from T_c (which is 585°C for magnetite [1937*i*] may be denoted the thermoremanence J_{rc}, and is equal to the natural remanence J_{rn} for recent rocks undisturbed in position while cooling. It is higher when H is higher. The field is always taken as the Earth's field of about 0.40 to 0.45 oersted.

§ 4. The following characteristics of all ferromagnetic substances are well known: The remanence J_{rs} is always greater when the coercive force H_c* is greater and lower when the external demagnetizing force H_d is higher. H_d depends on the shape and susceptibility of the ferromagnetic body and on its distance from other ferromagnetic materials. When the distance is of the order of body-size or larger, for a form which

*The coercive force H_c given here is the magnetic field which breaks the magnetic block of a unicrystal in smaller pieces and makes random distribution of nearly parallel orientation of blocks or an average which brings about a random distribution of large units in non-homogeneous bodies; it reduces to zero the apparent magnetization of the material whatever its form, size, and concentration. The coercive force of magnetization, $J(H_c)$ [1933*h*, p. 351, 1935*l*], is about the same as the coercive force of induction $B(H_c)$ (commonly designated as coercive force and shown by the induction hysteresis-loop) for soft iron but is somewhat higher for materials with a lower value of K; for materials with $K<1\times10^{-1}$, such as are studied here, it is much higher. As it is not possible to calculate the true values of $J(H_c)$ for the ferromagnetic materials in rocks whose shapes are very variable (see § 1), the apparent value of $J(H_c)$ was always preferably measured. The true value can be calcuated for the approximately isometric powders, because all the ferromagnetic materials with known K_0 measured here were embedded in a medium with $K<10^{-5}$ and so distant from one another so as not to be influenced by the magnetic induction of the neighboring grains. Compressed ferromagnetic powders without an insulator give results which cannot be compared with rocks and which cannot be reduced to true values. Only in the case of minerals with a low value of K, such as hematite, is there no difference between the apparent and true value for the case of dilated or compressed powders.

The mechanical force of H_c acting on the whole block of Type I (see § 4) of a unicrystal grain is H_cJ_{rs} may be analogous to the mechanical force necessary for the rupture of the surface of a liquid adhering to a glass plate, the boundary planes having adhesion or repulsion perhaps with transitions between both. H_c depends on the volume-forces of the homopolar bonds; it decreases with size, the phenomenon being roughly analogous to a thick plate coated more or less firmly below a sustaining ring, acted on by gravity which breaks it when the plate is too large. Of course 100 such plates of same size and properties in one cc but independent of one another will all break for the same value of gravity ($=H_c$), like a ferromagnetic substance with grains of the same size and orientation with a steep hysteresis-loop and sharp H_c. The so-called virgin curve for a grain with homogeneous space-lattice is the curve for many small blocks of Type I or random orientation which have been obtained in breaking the whole block by special treatment.

is very elongated in the direction of the field, H_c seems to vanish completely if the material is a homogeneous unicrystal [1926*d*, 1930*f*]. Multi-crystalline ferromagnetic substances, like chemically pure artificial magnetite, show an internal textural demagnetizing force [1931*b*], because a border face has a different value of K on the two sides when the two crystal-grains, which are also regular as in magnetite, are not orientated exactly parallel. H_d vanishes for low values of K for all shapes of the body.

At a given temperature the action exerted on a ferromagnetic homogeneous body by a magnetic field increasing from zero, may be indicated as follows: (*a*) In the fusing of the majority of small blocks of Type I (the magnetic elements of J. A. Ewing and P. Weiss) into one block or one system of combs (patterns of F. Bitter) with parallel spins, probably arranged in the principal direction of the crystal nearest to the field-direction; this order is reached discontinuously in jumps connected with Barkhausen effects. (*b*) A continuous rotation of blocks of Type II which are constrained by the space-lattice to essentially other directions, stresses also having an appreciable influence [1930*h*]; perhaps these blocks are partially fused together with blocks of Type I. (*c*) A continuous rotation, more accurately described as a precession, against the thermal agitation given by the formula of Langevin and P. Weiss for small fields and by the formulas of P. S. Epstein and of H. A. Kramers for intense fields (see theories of P. Weiss, W. Heisenberg, F. Bloch, N. Akulov, F. Bitter, K. Honda, and other authors). The electron-spins of each block are related through the exchange-integrals (Heisenberg) but each spin is movable to a certain degree and is affected by thermal agitation, increasing with increasing temperature.

If all blocks are parallel, there is a degree of saturation appropriate to a given temperature. Complete saturation is reached only when all the spins in the blocks are parallel despite the thermal agitation of their carriers, that is, for an infinitely strong magnetic field or at absolute zero so far as the thermal agitation becomes zero.

The effect of (*a*) depends on the magnitude of H acting against the true H_c; the latter holds the block-arrangement in the position it has acquired. For the space enclosing each unicrystal grain H_c depends on the diameters of the undisturbed space-lattice (see § 6); H_c of a multi-crystalline body has only a statistical definition and the phenomenon of Sixtus and Tonko enters.

Upon heating to near the Curie point, H_c decreases and vanishes [1933*g* and *g*′, p. 472] and a parallel order of the majority of spins of Type I can be obtained in a weak field of 0.4 oersted. Therefore the nearness of the approximation to a parallel order depends on H_d, on (K-T)-curve, and on the (H_c-T)-curve. With rising temperature, the maximum of K is also shifted to weak fields as is well known.

The observable magnetic effect at these high temperatures is weak for J_k as well as for J_r. For these high temperatures J_r is latent because of the thermal agitation of the carriers of the spins. While the body is cooling, the orientation of the block would remain the same, if the external and internal demagnetizing forces increasing with K are not higher than the true value of H_c plus or minus the outer field. The thermal disorder of the spins decreases and the magnetic effect of J_{rc} thus becomes larger and observable.

It is therefore advisable to observe at the lowest temperature suitable for the measuring apparatus which for a very sensitive non-evacuated magnetometer is room-temperature, for example, 18°C.

§ 5. J_{rt}, the thermoremanence, depends more on H_c and H_d than does J_{rs}, for a given shape of grain, both taken at the temperature when J_{rt} is subjected to the field of 0.4 oersted. This may be explained by a decrease of H_c correspondingly larger than that for K at high temperatures and by the relatively higher value of K_0 (K_0 for J_{rc} at high temperatures is nearer the maximum than at lower temperatures).

For a homogeneous pure unicrystal of such small dimensions that H_c does not vanish (see § 6) and in such a form that H_d tends to zero, $J_{rc} \rightarrow J_{rs}$ the thermoremanence for 0.4 oersted for some substances (pure iron) approaches the remanence of the strongest fields J_{rs} and the latter comes, for long, small rods of pure unicrystal iron [1937*g*], near (0.94) to the saturation-value J_{ks}. For nickel, magnetite, and hematite, the proportion of blocks I to blocks II (see above) is smaller [1937*g*]; it depends on the direction of the field relative to those of the crystal-axes.

Besides the thermoremanence J_{rc}, which is the most important cause of residual magnetism in nature, a strong residual magnetization can be impressed by the Earth's field at temperatures between about 100°C and 500°C during the time of lattice-changes in magnetite which result very probably from unmixing of Fe_2O_3 (see Part II). This may be called the *crystallization-remanence* J_{rl} (in electrolytically deposited iron at 20°, the effect found by Maurain [1901*b*, 1902*b*, 1911, 1924*c*]). As magnetite is generally assumed to crystallize in eruptive rocks above $T_c = 585°C$, the crystallization-remanence does not become effective in case lattice-changes do not occur at lower temperatures (see Part II). The phenomenon was not observed for hematites and ilmenites. For unmixing of TiO_2 on heating titanomagnetite without Fe_2O_3, crystallization-remanence was not observed with certainty.

In some hematites a spontaneous crystal-magnetization in certain directions was observed, the intensity of which seemed to depend partly on the direction of the Earth's magnetic field [1937*g*]. This crystal-magnetization, however, cannot greatly influence J_{rn} because of the random distribution of ferromagnetic material.

§ 6. In my opinion the most important new facts in ferromagnetic research relating to this subject are the following:

(a) It has been shown that for pure undisturbed ferromagnetic crystals of large size (>1 mm), H_c is small [magnetite 1896*a*, hematite 1937*g*]. For a pure iron-crystal H_c becomes very small (0.05 oersted) [1926*d*, 1930*f*], and the remanence very unstable [1930*f*]. The maximum susceptibility is high and is reached immediately in a low field, the hysteresis-loop approaching somewhat two long vertical and two small horizontal lines [1930*f*, 1937*h*]. Multicrystalline material, even though very pure, has an internal textural demagnetizing force so that K is lower than for multicrystals (see Part II). Owing to the interfaces, H_c never tends, for unicrystalline material, to zero but to a finite constant value depending on the size of grains, and J_{rs} is always lower than the magnetization for saturation, J_{ks}. An increase of H_c with decreasing grain-size was first found in the case of pure cobalt, iron, nickel [1924*c*, 1927*c* and *d*, 1928*c* and *d*, 1929*h* and *i*, 1930*e* and *g*, 1932*f*—as J_{rs} does not change much, the hysteresis-loss increases, 1926*f*] and in the case of magnetite

for corresponding values of H_c for approximately the same shape of grains and packing density [1935*d*]. H_c becomes greatest for small grains of hematite [1937*g*] where, on account of the low value of K_0, the true and apparent values are identical, the increase beginning for grains of five mm downwards. The grain-size can usually be determined by optically visible boundaries; interfaces (empty discontinuities of about 0.05μ) are sufficient as in artificial multicrystalline magnetite. But if layers of some metals like aluminum are coated firmly on the grains, it seems that H_c can decrease [1928*d*, 1937*e*] and the maximum permeability increases; the mobility of magnetic blocks seems, therefore, to depend on the qualities of the boundary-face. In fresh rocks magnetite-grains have no superficial metallic layers and hence only an increase in H_c is observed, for decreasing magnitudes of grain-size. It cannot be stated whether discontinuous changes in the space-lattice, for example, by the introduction of TiO_2, have any influence.

(*b*) The apparent and true permeability and K decrease with decreasing grain-size in strong and in weak fields up to 2600 oersteds [first confirmations 1916*b*, 1917, p. 415, 1924*c*, 1928*h*, principally 1935*d*, 1935*a*, 1935*c*] and the maximum of the apparent permeability is shifted for a stronger field and decreases [1919*a*, 1926*f*, 1929*e*, 1930*b*, principally 1935*c*]; both facts being shown in the case of compressed powders or grains of magnetite; hematite shows a strong decrease in the true value of K for a field of 700 oersteds [1937*a*]. The decrease must exist also for a field of 0.4 oersted because the calculation according to the correct formula [1931*a*, 1934*b*], using the volume-percentages of fine-grained magnetite in basalts observed with the microscope, gives a much lower value of K_0 than for large grains with $d > 0.1$ mm [1930*b*, 1935*g*, p. 210].

Comparing the curves [1896*a*, 1919*a*, 1930*b*, 1935*c*] it may be said that the maximum value of K_m also becomes less pronounced, the smaller the size of grain of any ferromagnetic material (see note 1 at end paper).

If the grain consists of only one crystal and one magnetic block, the hysteresis or, more accurately speaking, the block-order prevails, K being like all conventional ferromagnetic constants only a derived quantity; it is small except when the outer field is equal to H_c, that is, when the magnetization of the block changes its direction. For a single small homogeneous crystal with a majority of spins of Type I, the hysteresis-loop therefore approaches two horizontal or two vertical lines, both large (cycle of P. Weiss, Ch. Maurain, and R. Forrer).

These conditions seem somewhat approximated—the very small magnetic grains not all being of the same size—by an obsidian of Lipari Island ($H_c = 750$ oersteds, $K_0 = 1 \times 10^{-5}$, and $J_{rs} = 3.3 \times 10^{-4}$) and by a quartz porphyry (Bitterfeld, Halle, Pr. D., $H_c > 1700$ oersteds, $J_{rs} = 5 \times 10^{-3}$, and $K < 1 \times 10^{-5}$). [For a large unicrystal with $H_d = 0$ we have: J_{rn} (old)$\rightarrow 0$; J_{rc} (for 0.40 oersted)$\rightarrow J_{rs} \rightarrow a \cdot J_{ks}$. For very small ones: J_{rn} (old)$\rightarrow J_{rc}$ (for 0.40 oersted)$< J_{rs} \rightarrow a \cdot J_{ks}$.] Titanomagnetite, that is, magnetite with FeO and TiO_2 in excess, and pyrrhotite behave with respect to the influence of grain-size like pure magnetite. Hematite and ilmenite are still more sensitive to size of grain.

(*c*) According to § 4, J_{rs} increases for isometric grains with decreasing size because H_c increases, while K_0 and therefore also H_d decrease; J_{rc} increases also (see § 4) but seems not to approach asymptotically the whole value of J_{rs} for a field of 0.4 oersted.

§ 7. The eruptive rocks measured for cubes of 4-cm side are often non-homogeneous magnetically, sometimes also anisotropic [1930*c* and *d*]. Absolute measurements with an error of more than ten per cent are therefore mostly useless; it would, however, be expedient to observe the relative changes by heating the ferromagnetic substances to an accuracy of ±5 per cent. Non-metamorphized sediments, as far as measured, have no residual magnetism.

The value of J_{rn}, measured for a cube of 3- to 4-cm side, is lowered because of movements during the solidification of the rock. Large movements below the Curie point of pure magnetite (585°C) in cubes of small dimensions were observed by dissecting the cube of 4-cm side into eight cubes of 2-cm side and measuring the three components of J_{rn} for each. The components are sometimes very different as in the case of a young tertiary basalt [1932*d*, p. 207—for other examples see Part II] thus confirming the view that volatile agents have an important rôle in making the rock a viscous fluid mass [1929*f*, p. 247] even for temperatures down to about 400°C—a fact hitherto unnoticed by petrographists. An alpine serpentine [1932*d*, p. 208] was probably distorted by crushing. The average value of J_{rn} for such a whole cube was thus necessarily lower than the value of J_{rn} for its parts.

Movements of the cube en mass due to the upturning of large lava-masses during the cooling can be shown, using comparisons of the directions of J_{rn} in different samples [1904*c*, 1905*a*, 1906*b*, 1926*c*, 1931*d*, 1930*c* and *d*, p. 147, in basalts]. The differences in quickly cooled lava are small but often reach 10° to 15° [1925*b*, p. 146 ff.].

Sometimes the movements can be detected only in one cube and without dissection, by noting the components of J_{rn} acquired at higher and lower temperatures, for example, above and below 400°C both of which can be calculated from the observational data [1935*g*, p. 209, and Part II]; but often only one component is present.

The result of the movements is always to make J_{rn} lower than J_{rc}. The so-called poles on vertical rock walls [see 1897*c*, 1912*c*] are chiefly the result of movements which change the direction of J_{rn}, an effect observed long ago [see 1848, p. 156, etc., 1912*c*, pp. 123, 125, 1897*c*, p. 67]. For deducing the direction of the terrestrial field during cooling of the rock by measuring the direction of J_{rn}*, and the age of cooling of the rock by measuring (J_{rn}/J_{rt}), the following considerations seem necessary:

(*a*) Proof of movements or of their absence; movements have lowered J_{rn} and changed its direction.

(*b*) Proof of absence of magnetite with large excess of Fe_2O_3 (see Part II) because the formation of Fe_2O_3 by hydrothermal oxidation of magnetite as well as by separation can arise at relatively low temperatures during long geologic periods and produce new crystallization-remanence (see § 5).

(*c*) Measurement of T_c, which should not be below 200°C to 300°C, since heating to 200°C after the first cooling may be produced at great depths or under other conditions favorable to a high geothermal gradient (dT/dZ).

(*d*) When the influences mentioned under (*a*), (*b*), and (*c*) produce

*The observations hitherto made seem to lead to the conclusion that during geological periods with strong volcanic activity, the Earth's field has changed direction; but with the exception of reference 1925*b*, and partly of 1905*a*, 1906*b*, 1931*d*, and 1932*h*, observations were casual and movements in the cooling magma have sometimes perhaps led to erroneous conclusions.

no disturbance, the direction of J_{rn} is that of the Earth's field during the first cooling from the Curie point downwards and the age may be estimated by measuring the characteristic constants influencing the rate of spontaneous decrease with time (see § 8).

§ 8. *Ferromagnetic constants of rocks*—H_c is independent of the quantity of ferromagnetic materials for concentrations occurring chiefly in rocks, but depends on grain-size; for example, for larger hematites and perhaps also titanomagnetites, H_c becomes the same as for small grains of pure magnetite.

J_{rs}, J_{rc}, J_{rt}, and K_0 depend on the quantity of material; J_{rs}, J_{rc}, and J_{rt} in rocks of concentration p (in volume-percentage divided by 100) are proportional to p up to $p \simeq 0.1$, K_0 only for $p<0.01$ or up to $p=0.05$ when $K_0<0.1$; these conditions are chiefly fulfilled when the grains have a random distribution, but the latter state does not always occur.

T_c for H_c and J_r of pure magnetite is 585°C, of hematite 710°C [but cf. 1937*i*] of pyrrhotite 385°C. Magnetite with an excess of $FeO\text{-}TiO_2$ has a lower value of T_c [1932*a*] than pure magnetite and is stable at atmospheric pressure, provided that oxidation cannot take place. Plotting T_c as ordinate and $p' = Fe_2O_3/Fe_3O_4$ in grams as abscissa one gets a straight line [1919*b*, 1932*a*]. $T_c = 20$°C for $p=0.22$, that is, for 0.63 FeO against 0.37 Fe_3O_4.

Magnetite with an excess of more than one per cent of Fe_2O_3 is probably unstable at temperatures lower than 800°C for low pressures (<1000 atm). [For the case of 1388°C, 23 per cent of Fe_2O_3 at one atm of dry air, see 1935*f*.] It separates rapidly above 200°C at one atm (see Part II). Magnetite with TiO_2 in the space-lattice has probably a somewhat higher T_c for J_{rs} than without it [1937*g*; 1932*a*, 1935*m* state T_c would not be much changed by TiO_2] but slowly unmixes during heating [1925*d*, 1926*b*]. The magnetic behavior of pure magnetite and of magtite with FeO in excess, is well known (see Part II).

K_0 decreases with decreasing size while J_{rs} increases rapidly and J_{rt} still more (see § 6). Therefore H_c, $(J_{rs}/K_0) = R$ (both measured on fresh, not on heated, material), and $(J_{rt}/K_0) = Q$ or $(J_{rs}/J_{rt}) = S$ are not independent parameters [1933*a*,* 1934*b*, 1935*g*] but characteristic of the material as well as the size. The value of T_c is most probably characteristic only for the mineral but often cannot be determined because of unmixing**; the intensity of the latter can be seen by the changes of J_{rs}, K_0 and H_c of heated as against fresh material. All these indications furnish a hint as to when one ferromagnetic substance preponderates as is shown in Part II where the constants are given.

§ 9. A strong artificial magnet loses part of its residual magnetism J_r, at first rapidly, then slowly, a fact known for more than a hundred years and confirmed for rods of certain magnetites [1919*a*] Old eruptive rocks have lost most of their J_{rn}; rocks of recent geological age have retained it [1932*d*, 1935*g*].

For the rocks consisting chiefly of very small grains of magnetite, the stability of J_{rc} and J_{rn} at 20°C against true spontaneous decrease [1919*a*], shocks [1925*b*, 1932*d*], large variations of the outer magnetic field [1935*k*,

*The small magnetite grains $d<10\mu$ occurring in other minerals, in the so-called non-attracting portion of powdered rock, contribute therefore much more to J_{rt}, J_{rs}, and much less to K_0 than the larger attracting grains, a fact which explains some previous results [1933*a*].

**Unmixing takes place very slowly, and only partially in well-isolated grains of $d \leq 1\mu$ in more or less vitreous effusive material.

1937*b*] and of temperature ($\pm 50°C$) is higher than for rods of the same materials and much higher than for rods or discs of pure homogeneous material of large size (1 mm or more) with higher K_0 (see § 6) and higher H_d and with low H_c. The observations on rocks seem to permit some preliminary conclusions: The higher the value of T_c [1935*g*, 1925*b*, compare 1932*a*, p. 467] and of H_c, the greater is the magnetic stability. Rocks with low T_c [probably 1936*b*, compare 1929*a*, p. 119, 1937*c*] are much less stable magnetically. The functional relation is not known, the difficulties being as follows: A single isolated unicrystal grain would retain J_r as long as disturbances offer no stronger force than that corresponding to $H_c—f{\cdot}H_d$ for the same time and condition where f is a constant.. H_c is characteristic for the mechanical resistance to changes of J_r and to disintegration of the magnetic block by a magnetic field; the two phenomena are probably related or identical.

Effects disturbing J_{rn} in rocks are as follows: (*a*) Disintegration of the space-lattice by chemical changes (hydroxidation and hydrothermal action); (*b*) seismic shocks; (*c*) magnetic variations and also in some geologic periods the inversion of the Earth's field; (*d*) some concentration of thermal energy in a small part of the space-lattice of the block according to the law of probability; (*e*) autodiffusion, that is, place-changes of atoms. A magnetic reconstitution of the blocks can be effected only by an outer field and probably not in the original manner. The process of spontaneous decrease of J_r goes on until the blocks are arranged in correspondence with the outer field. Finally a very small value of J_{rn} would remain, the same as on the virgin curve for 20°C and 0.4 oersted.

If, in a multicrystalline body (not a rock), many unicrystal grains are near together, they produce a mutual magnetic induction-effect and thus apparent H_c, or the outer field necessary for demagnetization, is lowered as compared with H_c for the single grain, while the true H_c remains the same. On the other hand, the mutual magnetic potential-energy aids the decrease. The upturning of one magnetic block in such a continuously metallic body is propagated to other blocks by a wave as the studies of the Barkhausen effect have indicated. The disturbing effects (*d*) and (*e*) give the true spontaneous decrease of J_r, the transition being to a state with lower potential-energy; it begins when the magnetization (see end § 4) produces larger effects. Therefore, with a temperature lower than T_c, the decrease should become larger but, like all reactions with falling temperature, the rate of decrease and the transition become smaller. Possibly an optimum temperature for maximum decrease exists which is different for each material, but it has not been found for magnetite [1937*g*]. J_{rc} seems to depend within limits of ten per cent on the rate of cooling (in these experiments, about one to two hours from T_c to 20°). J_{rn} in recent rocks, where cooling took place during some thousands of years and without internal movements, is, for experiments in the laboratory, within $\pm$ 10 per cent the same as J_{rc}.

The true spontaneous decrease with time, at the temperature of the Earth's surface, cannot be studied in the laboratory because the effect produced through millions of years cannot be shortened by the use of higher temperatures on the basis of theoretical calculations (see above). Therefore, the decrease-function must be sought empirically for the principal types of ferromagnetic substances in rocks of known age. But

the value of J_{rc} which must be compared with J_{rn} cannot always be obtained. Magnetite with Fe_2O_3 is unmixed by heating at atmospheric pressures. The small difference in cell-edge and density between hematite with TiO_2 and magnetite with TiO_2-Fe_2O_3 (titanomaghemite) suggests that some 100 atm were perhaps sufficient and necessary for the stability of titanomaghemite in nature, but this would require expensive apparatus.

§ 10. For the classification of types, the chemical analysis of the small grains in each rock would necessitate a continuous collaboration with chemists and would require a very difficult separation from intercalated lamellae of ilmenite, etc. There remains the magnetic analysis by characteristic constants and heating curves.

As will be seen later in Part II of this paper, rocks may be tentatively classified in the three types with the aid of the curve given by heating for $J_{rn} \pm J_{rt}$ or $J_{rc} \pm J_{rt}$ and with the typical constants $(J_{rc}\ K_0 \times 0.45) = Q_t$, $(J_{rs}/K) = R$, $(J_{rs}/J_{rt}) = S$, H_c, T_c, and their changes by heating.

Class I, magnetite, pure or with FeO and some TiO_2 (titanoiozite), is suitable for the study of the direction of the Earth's field at the time of the first cooling of the rocks and for evaluation of their geological age, provided $T_c > 300°$ and there is an absence of movements (see § 7).

Class II, containing magnetite with much TiO_2, can be used, in so far as the absence of notable movements has been ascertained, to measure the direction of magnetization, but not usually for estimating the age.

Class III, titanomaghemite, etc., showing strong changes and unmixing by heating cannot be used either for measuring the direction of magnetization or estimating the age.

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(*e*) F. T. Wall, Engineer, Aug. 13, 183 (Min. Metall., 431).
(*g*) Unpublished observations by the author of 1933-1936.
(*h*) P. P. Cioffi, H. J. Williams, and R. M. Bozorth, Phys. Rev., **51**, 1009.
(*i*) R. Chevallier and Z. E. Bégui, Bull. Soc. chim. France, No. 194, 1735.

Appendix on Notation

K_0 = volume-susceptibility for weak fields of less than two oersteds; it is constant for small grains of magnetite, etc., in rocks for fields up to about two oersteds.

χ = susceptibility per gram.

J = magnetization per cc.

J_r = remanent or residual magnetization or remanence in field zero acquired in the field H.

J_{rn} = natural remanence of rocks or minerals.

J_{rs} = maximal remanence—in the theory of ferromagnetism designated mostly as remanence; it depends on the shape of the body.

$(J_{rs})_{tr}$ = true remanence totally free from demagnetizing force H_d.

H_d = demagnetizing force becomes zero for a very elongated body, or for a ring, or for a piece of ferromagnetic material between poles of soft iron which has a very elongated shape or has the shape of a circular ring.

In rocks, only the apparent values of J_r, J_{rs}, etc., can be measured when the grains have a given shape. If the values for a mineral are given, true values of quantities measured are meant, but these are only relative if the mineral is not a unicrystal and therefore internal faces occur giving smaller H_d; the grain-size also enters for K_o, H_c. For powders most authors give apparent values dependent on compression or density; sometimes the true values can be calculated.

J_{rc} = remanence of the body, rock, mineral, etc., acquired by cooling from the Curie point C_p (temperature T_c) in the field 0.4 oersted to 20°C.

J_{rt} = remanence acquired by cooling from t to 20°C in 0.4 oersted.

$J_k = KH$ = magnetization in the field H.

$B = 1 + 4\pi KH$.

J_{ks} = maximal magnetization for a given temperature.

J_{rl} = remanence impressed by a magnetic field during changes of the space-lattice, for example, by unmixing; it is much greater than J_r for the same field but without changes.

Note 1: The shifting and the decrease of K_m, the increase of H_c, while J_{rs} remains constant, in the case of a unicrystal may be easily connected together by the theory of P. Weiss [1907] which apart from the constant gives also the rule of Gumlich and Schmidt.

(*Part II will appear in September issue*)

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ERDMAGNETISCHE AKTIVITÄT—V

Von J. Bartels

Abstract—The tables of monthly and annual means for the measures u and u_1 of terrestrial-magnetic activity given in this Journal [1-4] for the years since 1835 are continued for the years 1935 and 1936 and supplemented by preliminary values, based on observations at Niemegk alone, up to March 1938. The recent sharp increase in magnetic activity is discussed and compared with the Zürich sunspot-numbers R. The lag of u behind R is again noticeable. 1937 appears to be the most active year magnetically since the years around the high sunspot-maximum 1870, although no individual storm of outstanding intensity occurred. Three successive storms gave the high value $u=2.74$ to the month January 1938, a value comparable only with such well-known months as November 1882, August 1917, March 1920, or May 1921. The different degree of terrestrial-magnetic quietness reached during the last four sunspot-minima is discussed. The minima of 1901 and 1913 were appreciably quieter than the minima of 1923 and 1933; this magnetic evidence agrees with solar observations in so far as the Sun was free of spots on more days around 1901 and 1913 than around 1923 and 1933.

§ 1. Das Mass u für die erdmagnetische Aktivität ist definiert als der durchschnittliche absolute Betrag der Aenderungen der Tagesmittel der Horizontalintensität auf dem magnetischen Aequator der Erde von Tag zu Tag, gemessen in der Einheit 0.0001 CGS $=10\gamma$. Man kann u auffassen als Mass für die Schwankung der Stärke des Ringstroms, oder als Mass für die erdmagnetische Wirkung solarer Korpuskularstrahlung; diese unterscheidet sich deutlich von der Intensität der solaren Ultraviolettstrahlung, die besser durch das Ausmass des erdmagnetischen sonnentägigen Ganges an ruhigen Tagen gemessen wird. u misst die durchschnittliche Häufigkeit und Stärke grösserer erdmagnetischer Störungen, während die Monatsmittel der internationalen erdmagnetischen Charakterzahlen C mehr die Häufigkeit eines schwächeren Störungsgrades kennzeichnen, oder das Fehlen besonders ruhiger Tage.[5]

Aus den Monatsmitteln für u wird eine zweite Masszahl u_1 abgeleitet: für Werte von u zwischen 0.0 und 0.6 ist $u_1=100u-30$; für höhere Werte wächst u_1 langsamer bis zum grössten Wert $u_1=140$. Das Mass u hat den Vorzug anschaulicher Bedeutung; das Mass u_1 eignet sich besser für die Untersuchung von Korrelationen zwischen erdmagnetischer Aktivität und Sonnentätigkeit, denn es ist so gewählt, dass die Häufigkeitsverteilung der Monatsmittel von u_1 ähnlich ist wie diejenige der Züricher Sonnenflecken-Relativzahlen R. Für die Zeit 1835-1930 sind die Zahlen u und u_1 in der ersten dieser Mitteilungen[1] gegeben, mit ausführlicher Diskussion über die Berechnung von u und den Zusammenhang mit der Sonnentätigkeit. Kürzere Mitteilungen setzen die dortigen Tabellen fort für 1931 32[2], 1933[3], und 1934[4]. Zur besseren Uebersicht werden diese Mitteilungen von jetzt ab numeriert werden.

§ 2. Folgende 7 Stationen wurden, mit gleichem Gewicht, für die Berechnung von u für die Jahre 1935 und 1936 benutzt (Umrechnungsfaktor k in Klammern): Huancayo (0.84); Honolulu (1.14); San

[1]Terr. Mag., **37**, 1-52 (1932) (die Tabelle auf S. 9 gilt für u, nicht für u_1; die Tabelle für u_1 ist auf S. 15).
[2]Terr. Mag., **39**, 1-4 (1934).
[3]Terr. Mag., **40**, 265-266 (1935).
[4]Terr. Mag., **41**, 374 (1936).
[5]Diskussion mit G. van Dijk, Terr. Mag., **40**, 371-382 (1935).

Juan (1.24); Watheroo (1.30, nur 1935); Tucson (1.44); Cheltenham (1.55); Niemegk (1.73). Für Niemegk wurde anstelle der Horizontalintensität H die Nordkomponente X benutzt. Ausserdem sind vorläufige Werte mitgeteilt, die auf Beobachtungen in Niemegk allein beruhen.

Tabelle 1—*Monatsmittel für u und u_1 (definitive Werte für 1935/36, provisorische Werte für 1937 und 1938)*

Table 1—*Monthly means for u and u_1 (final for 1935/36, preliminary for 1937 and 1938)*

Mass	Jahr	Jan.	Feb.	März	Apr.	Mai	Juni	Juli	Aug.	Sept.	Okt.	Nov.	Dez.	Jahr. Wert
u	1935	0.73	0.97	0.69	0.65	0.75	0.79	0.79	0.60	1.00	0.93	0.77	0.70	0.78
	1936	0.75	0.79	0.71	0.94	0.82	1.10	1.16	0.73	0.79	1.13	1.32	0.98	0.94
	1937	0.93	1.05	1.48	1.88	1.69	1.58	1.64	1.52	0.99	1.74	0.87	1.20	1.38
	1938	2.74	1.12	1.17	1.74	.....	.....	.....	.....	.....	.....	.....	.....	.....
u_1	1935	42	63	39	35	44	48	48	30	65	60	46	40	47
	1936	44	48	41	61	50	72	77	42	48	75	86	64	59
	1937	60	69	95	110	104	99	102	97	64	105	55	79	87
	1938	133	74	77	105	.....	.....	.....	.....	.....	.....	.....	.....	.....

Der Verlauf im elfjährigen Zyklus ist aus der folgenden Tabelle der Jahresmittel ersichtlich (Anschluss an die frühere Tabelle[2]).

Tabelle 2—*Jahresmittel für u und u_1, und für die Züricher Sonnenflecken-Relativzahlen R (das Mittel für 1933.0 ist aus den 12 Monaten Juli 1932 bis Juni 1933 berechnet, das Mittel für 1933.5 aus den 12 Monaten Januar bis Dezember 1933, usw.); die Werte für 1937.0 und 1937.5 sind provisorisch*

Table 2—*Annual means for u, u_1, and the Zürich sunspot-numbers R (1933.0 = mean July 1932 to June 1933; 1933.5 = mean January to December 1933)*

Mass	Jahr									
	1933.0	1933.5	1934.0	1934.5	1935.0	1935.5	1936.0	1936.5	1937.0	1937.5
u	0.68	0.67	0.68	0.67	0.70	0.78	0.82	0.94	1.23	1.38
u_1	38	36	38	36	39	47	50	59	77	87
R	9	6	5	9	16	36	58	80	104	114

Figur 1 setzt die frühere Kurve der Jahresmittel 1835-1930 fort. Die Massstäbe für R und u_1 sind so gewählt, dass die Ordinaten beider Kurven gleiche Streuung haben; deshalb ist die Ordinaten-

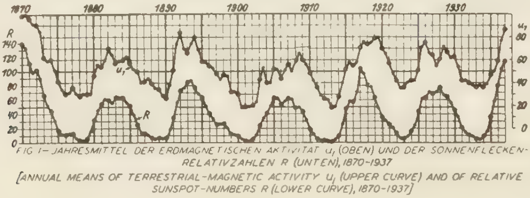

FIG 1—JAHRESMITTEL DER ERDMAGNETISCHEN AKTIVITÄT u_1 (OBEN) UND DER SONNENFLECKEN-RELATIVZAHLEN R (UNTEN), 1870-1937

[ANNUAL MEANS OF TERRESTRIAL-MAGNETIC ACTIVITY u_1 (UPPER CURVE) AND OF RELATIVE SUNSPOT-NUMBERS R (LOWER CURVE), 1870-1937]

Einheit für u_1 rund 1.6 mal grösser als für R. Auch im Anstieg vom Fleckenminimum 1933.8 lässt sich wieder das Nachhinken der erdmagnetischen Aktivität erkennen. Gleichen Sonnenfleckenzahlen im Anstieg zum Maximum entsprechen geringere u_1=Werte als im Abfall zum Minimum; in der Figur wird das deutlich durch das weiss gelassene Band zwischen den beiden Kurven, das im Anstieg zum Maximum schmaler ist als im Abfall zum Minimum. Diese Tatsache wird so gedeutet[1], dass die Flecken (oder die M—Regionen als Herde der Korpuskular—Ströme) zu Anfang des Zyklus, wegen ihres grossen Abstandes vom Sonnen-Aequator, weniger stark erdmagnetisch wirken als die äquatornahen Flecken gegen Ende des Zyklus.

1937.5 gibt den höchsten Wert für u und u_1 seit 1872; der höchste Potsdamer Wert (u = 1.33 für 1892) seit Gründung des Observatoriums wird übertroffen durch $u = 1.38$ für 1937. Ein besonders heftiger magnetischer Sturm wurde 1937 nicht registriert; die hohe Aktivität beruht auf der Häufigkeit kleinerer Stürme. Der Monat Januar 1938, mit $u = 2.74$, verdankt diese hohe Aktivität den drei aufeinanderfolgenden Stürmen vom 16., 22., und 25. Januar; ähnlich hohe u-Werte haben seit 1872 nur die bekannten Monate November 1882 (2.95), August 1917 (2.37), März 1920 (2.54), und Mai 1921 (2.70).

§ 3 Die verschiedene Tiefe der Minima in Figur 1 ist in der oberen Kurve auffallender als in der unteren. Die Epochen der letzten vier Fleckenminima sind[6] 1901.7, 1913.6, 1923.6, 1933.8. Die jeweils kleinsten ausgeglichenen Monatsmittel der Relativ-Zahlen R sind nach Brunner 2.6, 0.0, 5.6, 3.4. Diese 4 Zahlen unterscheiden sich zwar wenig, aber es ist bekannt[1], dass u auf Aenderungen von R in der Nähe des Minimums empfindlicher reagiert als in der Nähe des Maximums.

Um jeden Verdacht auszuschalten, das die verschiedene Tiefe der Minima von u oder u_1 wenigstens zum Teil durch eine Inhomogenität in der Reihe u hervorgerufen sein könnte (da im Laufe der Jahre die benutzten Stationen gewechselt haben), wurde folgende Rechnung angestellt: es wurden um jedes Minimum drei Jahre betrachtet, also 1900, 1901, 1902; 1912, 1913, 1914; 1922, 1923, 1924; 1932, 1933, 1934. Aus den 36 Monaten in jedem der 4 Abschnitte wurden für jede Station einzeln und unabhängig von den anderen—die jeweils 18 erdmagnetisch ruhigsten Monate ausgesucht, also 18 Monate mit den kleinsten Zahlen u für diese Station; aus diesen 18 Monatswerten wurde das Mittel gebildet. Die Beschränkung auf 18 Monatswerte von 36 verfügbaren Werten hat den Zweck, die erdmagnetisch gestörten Monate auszuschalten, die auch in der Nähe des Minimums auftreten können.

Jede Zeile in Tabelle 3 beruht ausschliesslich auf den Beobachtungen an *einer* Station. Da keine der Stationen in *allen* 4 Minimaljahren benutzt werden konnte, ist keine Zeile vollständig; es wird aber ganz klar, dass die Verschiedenheit der Minima sich in allen Stationen gleichmässig gut ausprägt. 1901 und 1913 erscheinen wesentlich ruhiger als 1923 und 1933; um 1901 war die durchschnittliche Aenderung der Horizontalintensität im erdmagnetischen Aequator von Tag zu Tag nur 4.2γ, um 1923 dagegen 5.7γ.

Die letzte Zeile gibt die prozentische Zahl p der Tage, in denen in den letzten 3 Jahren überhaupt Flecken auf der Sonne sichtbar waren;

[6]W. Brunner, Terr. Mag., **40**, 217 (1935).

sie stimmt überraschend gut zu den Werten von *u*. Zusammenfassend kann festgestellt werden:

Die Ruhe der Sonnentätigkeit während der Fleckenminima kann charakterisiert werden durch die prozentische Anzahl *p* der Tage, an denen in den 3 Jahren um das Minimum überhaupt Flecken auf der Sonne sichtbar waren; die erdmagnetische Ruhe kann charakterisiert werden durch den Mittelwert der 18 ruhigsten Monatswerte von *u*. Der Grad der Ruhe während der letzten 4 Fleckenminima war verschieden; diese Verschiedenheit ist in der Sonnentätigkeit und im Erdmagnetismus sehr ähnlich.

Tabelle 3—*Mittel der 18 niedrigsten Monatswerte von u, Zahl N der Tage ohne Sonnenflecken*[7], *und prozentische Anzahl p der Tage mit Sonnenflecken, in den drei Jahren um jedes der 4 letzten Sonnenfleckenminima*

Table 3—*Mean u for the 18 magnetically quietest months in the three calendar years around each of the four last sunspot-minima, the number N of days without spots, and the percentage number p of days with spots for the same three years*

Minimum		1901	1913	1923	1933
Bombay	*u*	0.41	0.43	0.58	....
Postdam	*u*	0.44	0.46	0.56	...
Batavia	*u*	....	0.43	0.60	...
Honolulu	*u*	....	0.44	0.55	0.53
Tucson	*u*	....	....	0.58	0.56
Watheroo	*u*	....	....	0.57	0.53
Mittel	*u*	0.42	0.44	0.57	0.54
N		728	700	377	471
p		34	36	66	57

Für die Zusendung von unveröffentlichen Tagesmitteln der Horizontalintensität danke ich dem Direktor des U. S. Coast and Geodetic Survey (Observatorien Cheltenham, Tucson, San Juan, und Honolulu) sowie Herrn Dr. J. A. Fleming, Direktor des Department of Terrestrial Magnetism, Carnegie Institution of Washington (Observatorien Watheroo und Huancayo).

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[7]Nach den jährlichen Mitteilungen des Greenwich Obs. in den Monthly Notices R. Astron. Soc., London.

NACHTRAG ZU DEM AUFSATZE* "UEBER DIE METHODE VON ARTHUR SCHUSTER ZUR ANALYTISCHEN DARSTELLUNG NUMERISCH GEGEBENER FUNKTIONEN AUF DER KUGELFLÄCHE"

Von Adolf Schmidt

Die Zusammenstellung der gebrauchsfertigen Formeln für die Koeffizienten $g^\sigma{}_n$ und $h^\sigma{}_n$, die am Schlusse folgen sollte, fehlt dort. Für die zonalen Funktionen $(\sigma=0)$ stehen die betreffenden Formeln auf S. 350, für die übrigen werden sie hier nachträglich mitgeteilt. Die Zahlenwerte der Faktoren der a_p und b_p (bzw α_p und β_p) findet man übrigens, und zwar auf 5 Dezimalen angegeben, in der Tabelle auf S. 353. Der hier versehentlich benutzte Index m ist mit σ gleichbedeutend.

Zum Schlusse sei noch ein prinzipielles Bedenken kurz erwähnt, das sich gegen die Verwendung der Fourier'schen Entwicklung geltend machen lässt, wenn es auch selten von praktischer Bedeutung sein wird. Es entspringt daraus, dass in diese Entwicklung die den verschiedenen Werten von θ zugehörigen Einzelwerte der k^σ und K^σ sämtlich mit gleichem Gewicht eingehen, während bei empirischen Grössen im allgemeinen ein wenigstens annähernd mit $\sin\theta$ proportionales Gewicht sachlich angemessen ist.

$$g^1{}_2=0.8502a_1-0.8502a_3 \qquad g^1{}_1=1.1781a_0-0.5890a_2$$

$$g^1{}_4=0.3493a_1+0.8732a_3-1.2224a_5 \qquad g^1{}_3=0.4208a_0+0.8417a_2-1.0521a_4$$

$$g^1{}_5=0.2614a_0+0.3268a_2+0.9149a_4-\ldots\ldots$$

$$g^2{}_2=1.2753b_1-0.4251b_3 \qquad g^2{}_3=1.3308b_2-0.6654b_4$$

$$g^2{}_4=0.2470b_1+1.3583b_3-0.8644b_5 \qquad g^2{}_5=0.3458b_2+1.3832b_4-\ldots\ldots$$

$$g^3{}_4=0.9241a_1-1.3861a_3+0.4620a_5 \qquad g^3{}_3=1.6299a_0-1.0866a_2+0.2716a_4$$

$$g^3{}_5=0.8471a_0+0.4941a_2-1.5529a_4+\ldots\ldots$$

$$g^4{}_4=1.6335b_1-0.8168b_3+0.1634b_5 \qquad g^4{}_5=1.4974b_2-1.1979b_4+\ldots\ldots$$

$$g^5{}_5=1.8941a_0-1.4206a_2+0.5682a_4-\ldots\ldots$$

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*Terr. Mag., **42**, 347-354 (1937).

REVIEWS AND ABSTRACTS

Schonland, B. F. J.: *The lightning-discharge.* Being the Halley Lecture delivered on May 28, 1937. Oxford, Clarendon Press, 1938 (19 with 8 figs.). 23 cm.

A summary is given of our present knowledge of the lightning-discharge, obtained by use of two devices of high resolving power in time, namely, the Boys camera and the cathode-ray oscillograph.

The first device consists of a camera in which there is a relative motion of lens and film and consequent distortion of the recorded image, in such a way that any portion which becomes luminous later than another is recorded as more displaced from its correct position than the earlier portion. In the Boys camera two diametrically opposite lenses move along a circle, the axis of rotation being perpendicular to and passing through the photographic film; these moving lenses give distortions in opposite directions. The distorted picture yields a "time-table" of the emission of light along the air-channel of the lightning-discharge.

The lightning-flash is generally made up of a number of separate discharges or *strokes*. As many as 40 such successive strokes have been recorded and the total duration of the whole flash sometimes approaches a second. Each separate stroke consists of a downward-moving luminous process termed the leader-streamer, followed upon arrival near the surface of the ground by a much more rapid and brighter return-streamer which traverses the same channel in the reverse direction. The typical leader-streamer of the first stroke proceeds downwards in a series of bright steps, each about 50 meters long with fairly regular pauses between each step. Changes in direction follow after each pause, also giving branches developing in steps. Branches are usually found only in the first stroke. When one of these step-streamers strikes the ground the return-streamer passes rapidly back from the ground to cloud, also running outwards along each branch.

The leader subsequent to the first stroke is not stepped but travels continuously to the ground as a fast-moving dart-streamer of light about 40 meters long, the stem of the streamer behind this luminous tip being only faintly illuminated. It travels more slowly, and may show some steps with shorter pauses, if the time-interval since the preceding stroke is unusually long.

The step-, the dart-, and the return-streamers have speeds of about 10,000, 2,000, and 20,000 km/sec, respectively. The step-streamer as a whole, proceeds with an *effective* velocity which can be as low as 100 km/sec and seldom exceeds 300 km/sec. There may be a fourth type of streamer (not photographed) termed a pilot-streamer with a real velocity corresponding to the effective velocity of the step-process. The brightness of a streamer-tip varies approximately as the third power of its velocity. The streamers emit light and their progress can be photographed because excitation as well as ionization of the molecules occurs in the strong electric fields at their tips. Current-strengths of a streamer may vary from about 160,000 amperes for a fast return-streamer to 0.1 ampere for a pilot-streamer.

The changes with time of the electrical characteristics of the discharge are investigated using a cathode-ray oscillograph attached to an electrode above or on the ground. Changes observed in the electric intensity correspond closely in time with changes shown in photographs, including those for the steps in the leader-streamer. All field-changes in South Africa, other than transitory ripples, are positive and involve firstly the slow lowering and secondly the sudden removal to ground of negative cloud-charge. The leader-process must therefore be a negative streamer proceeding from a cathode in the cloud and lowering the negative charge into the air and towards the Earth, which is positively charged. Upon contact with the ground the return-streamer proceeds upwards; both streamers involve downward motions of electrons.

It appears that the advance of a dart-leader involves ionizing processes by free electrons in front of the tip of the streamer itself, guiding the streamer along the previously formed channel. The tip of the return-streamer is positively charged, making the speed of advance very rapid along the trail having high electron-density produced by the leader.

Other lightning-discharges devote themselves to the neutralization of a large positive space-charge produced by electrical discharge from points on the ground and located in the air beneath the base of the thunder-cloud; the flash is then a heavily branched air-discharge. The positive space-charge shields the Earth itself from any very large electric field. The space-charge cloud-blanket may have to approach sufficiently near to a center of charge in the cloud to create a field sufficient for electric break-down. The paper confines itself to the description of established facts about the lightning-discharge and includes little discussion of controversial subjects.

E. H. Vestine

COIL-MAGNETOMETER AND EARTH-INDUCTOR A COMPARISON OF RESULTS OBTAINED AT THE ABINGER MAGNETIC STATION OF THE GREENWICH ROYAL OBSERVATORY*

By W. M. H. Greaves and W. M. Witchell

Dr. J. Egedal, Danish Meteorological Institution, Copenhagen, has recently made an examination of the results obtained at a number of magnetic observatories in the northwest of Europe, with special reference to the magnetic vertical intensity, Z, as derived from observations with earth-inductors. In the course of his investigation the values obtained in 1934 at Abinger, both with the inductor and with the Dye coil-magnetometer for directly determining Z, were compared, and it seemed to Dr. Egedal that discordances could most easily be explained as due to an effect of temperature in the magnetometer. He communicated this opinion to the Royal Observatory, Greenwich, and it was felt there that

Table 1—*Results of an analysis of the discordance between values of Z (inductor minus coil-magnetometer) obtained at Abinger Magnetic Observatory by the independent methods of earth-inductor and coil-magnetometer*

Reference	Period	No. of comparisons	Effect of wear per 10 days	Weight	Effect of temperature per 1° C	Weight	Mean-square error of R
	1934		γ		γ		γ
1	Jan. 1–Feb. 24	48	+0·072	124	+0·144	288	3·2
2	Feb. 26–May 5	55	+0·503	76	+0·779	153	4·3
3	May 7–June 2	24	+1·824	13	+0·284	115	4·3
4	June 4–July 11	32	+1·695	26	+0·107	197	4·3
5	July 12–Aug. 23	33	+2·558	29	+1·306	114	4·1
6	Aug. 24–Nov. 7	64	+0·424	145	+0·705	437	4·2
7	Nov. 8–Feb. 6	70	+0·883	466	+0·065	695	4·0
	1935						
8	Mar. 5–Apr. 4	26	+0·882	17	+0·407	207	2·9
9	Apr. 24–Sept. 9	107	+1·087	1087	−0·306	1219	4·0
10	Sept. 10–Dec. 31	85	−0·686	545	−0·175	740	4·3
	1936						
11	Jan. 1–Mar. 31	71	+0·361	475	−0·422	1298	3·9
12	Apr. 1–June 30	69	+0·261	149	+0·207	551	4·2
13	July 1–Sept. 30	77	+0·109	491	+0·481	312	4·4
14	Oct. 1–Dec. 30	70	+0·461	503	−0·157	463	3·7
	1937						
15	Jan. 1–Mar. 31	71	+1·432	409	+0·220	545	5·4
16	Apr. 1–July 15	87	+0·497	453	−0·132	609	4·9
17	July 16–Sept. 30	59	+0·472	223	+0·074	408	4·0
18	Oct. 1–Dec. 3	52	+0·840	167	−0·022	248	4·9

Weighted mean values from 1100 comparisons:

Effect of wear of bearings = $+0·056\gamma \pm ·013$ per diem.
Effect of temperature = $+0·001\gamma \pm ·058$ per degree C.

*Communicated by The Astronomer Royal, Dr. H. Spencer Jones.

the matter deserved a closer investigation than would have been possible to anyone not having full details of the observing conditions.

Accordingly the differences at Abinger in Z base-line value as given by inductor and magnetometer have been analyzed, taking all days in the years 1934-37 on which determinations were made by both instruments.

It should be explained that although in the construction of the Abinger inductor provision is made for removing end-play in the axis, this is not very readily accomplished, and the effect of wear on the bearings has consequently been allowed to accumulate, in general, until a convenient occasion arose to make the adjustment. In practice, after the Dye magnetometer had been constituted the standard instrument, the operation of adjustment was sometimes postponed beyond the limits of strict caution.

The equation of condition was assumed to be $ax+by+c=R$ where R = value by inductor minus value by coil-magnetometer of base-line; $10a$ = the number of days elapsed since the last adjustment of end bearings; b = temperature of the coil-magnetometer; c = the systematic difference between the values, that is, the difference when a and b are each zero.

The differences were grouped in series either in a period during which no adjustment of end-bearings took place or, if this period seemed unduly long, in an arbitrary period of approximately three months. There are 18 groups comprising 1100 comparisons in all.

Table 1 gives the least-square solution for x the "wear-coefficient" and y the "temperature-coefficient" from each group, the number of comparisons comprised in the group, the weight of the individual solutions (unit-weight corresponding to a single comparison of inductor and coil), and the mean-square error of R in each group. It will be seen that the effect of temperature, though apparently definite throughout the year 1934, was not significant in succeeding years and, in fact, the weighted mean from the whole series of comparisons is negligible within the error of observation.

Royal Observatory,
Greenwich, March 24, 1938

SOME ATMOSPHERIC-ELECTRIC OBSERVATIONS AT POONA

BY J. M. SIL

A continuous record of the Earth's electric field has been obtained at Poona since September 1930. Since 1935 arrangements were also made to take systematic measurements of the conductivity as well as of the dust, nuclei, and ionic contents of the air simultaneously at some appointed hour. In this preliminary report, all observations cover a period from 1935 to 1937 except those on potential-gradient which are from September 1930 to November 1937.

Poona is a rocky place, situated on a plateau formed on the eastern side of the chain of mountains, called the Western Ghats. Its position is latitude 18° 30′ north, longtitude 73° 53′ east, and its height above mean sea-level is 1830 feet. It is not an industrial center. During afternoons in summer, a cool sea-breeze blows from the Arabian Sea and raises a fairly good amount of dust. During the monsoon season (July to September) the sky is almost overcast on most of the days although it rains only occasionally. During September and October there are frequent thunderstorms. During winter (November to February) a strong inversion of temperature occurs almost every evening, followed sometimes by moderate haze or fog in the early morning. Considering the above it will be clear that the number of undisturbed days in a year is very small and observations extending over a long period, therefore, are necessary for the collection of sufficiently reliable data.

The potential-gradient was obtained from records of a Cambridge electrograph. The instrument is provided with a "radium" collector, the potential of which was recorded photographically with a Dolezalek electrometer. The recorded field was corrected by the "exposure factor", which was determined occasionally by arranging simultaneous observations on a "calm day" out in the open, following Simpson's method[1]. An ionium-collector standardized by the Carnegie Institution of Washington, was used for this purpose. For data given in this report, records obtained on the least-disturbed days only have been considered. The hourly values were computed from the records by evaluating the mean ordinate for the complete hour centered at 10^h (Indian standard time).

An Owen's dust-counter was employed for obtaining records of dust. Generally each record was prepared by drawing 200 cc of air and the counting was done under a microscope with an oil-immersion objective giving a total magnification of 600. For observation of dust, two records were generally taken, one immediately after the other, and the result given is the mean of the two. Hygroscopic dust-particles were precipitated by drawing in sample air in a cleaned chamber of Aitken-Ludeling counter. The condensed nuclei falling on the first expansion were counted and those falling on the subsequent expansion were also taken in consideration. The observation was repeated three times and the average of the three results was taken.

The number of positive and negative ions was obtained with an Ebert ion-counter. The apparatus was provided with a Wulf's bifilar

[1]G. C. Simpson and C. S. Wright, Proc., R. Soc. A, 85, 175-199 (1911).

electrometer and a Rosenmüller anemometer; the inner electrode of the instrument was raised to a potential of 200 volts, and about 400 liters of air, usually at a rate of 80 liters per minute, were drawn through the apparatus before the electrometer-reading was taken. The electrical conductivity of the air was measured directly with a Gerdien apparatus, which was fitted with a Wulf bifilar electrometer. The inner electrode was charged to 80 volts only and the fan was operated rapidly for three minutes before the electrometer was read. The Ebert and the Gerdien apparatuses were installed in a small room on a tower at a height of about 46 feet above ground. The room gets a good breeze and has on all its sides large doors and windows, which are fitted with wire-nettings. These wire-nettings almost served the purpose of a large earthed cage; the correction suggested by Swann[2] therefore was not applied to the results obtained with these instruments. For dust- and nuclei-observations samples were drawn from the layer of air at a height of about ten feet above ground. The electrometers used with the Cambridge electrograph and the Gerdien and Ebert apparatus were calibrated and tested periodically.

Mean values worked out for each month were all based on observations at 10 hours Indian standard time. All observations were taken simultaneously and the time taken to complete the observations was about 40 minutes.

Table 1—*Monthly averages, atmospheric-electric observations at 10 hours, Indian standard time, at Poona*

(Figures in parenthesis indicate the number of observations)

Month	Potential-gradient, F	Polar conductivity		Total conductivity, λ	No. small ions per cc, n		No. Aitken nuclei, N	Coarse dust particles, d
		$\lambda +$	$\lambda -$					
	volt/meter	($esu \times 10^{-4}$)		($esu \times 10^{-4}$)	$n+$	$n-$		
January	135 (32)	0.98	0.95	1.94 (24)	720	707 (15)	7390 (19)	21 (22)
February	119 (34)	1.07	1.05	2.12 (18)	740	690 (18)	6440 (25)	18 (21)
March	83 (30)	1.06	0.96	2.02 (20)	743	690 (14)	5299 (30)	24 (16)
April	66 (30)	1.52	1.50	3.02 (19)	796	755 (15)	4640 (26)	15 (15)
May	62 (30)	1.75	1.67	3.42 (20)	874	842 (15)	4840 (32)	12 (19)
June	64 (30)	1.82	1.73	3.55 (21)	1066	1054 (11)	4780 (27)	11 (15)
July	57 (26)	1.93	1.86	3.79 (17)	1011	999 (12)	4780 (29)	3 (12)
August	61 (32)	1.82	1.75	3.57 (27)	1066	1026 (15)	4980 (34)	2 (13)
September	62 (37)	1.67	1.63	3.30 (17)	957	906 (9)	5170 (24)	2 (12)
October	95 (26)	1.13	1.13	2.26 (18)	897	858 (8)	6760 (19)	10 (17)
November	124 (33)	1.09	0.96	2.05 (15)	790	753 (13)	7590 (19)	15 (19)
December	149 (30)	0.88	0.87	1.75 (14)	765	720 (10)	7420 (18)	17 (26)

The mean monthly values of the elements have been arranged in Table 1; these have also been plotted in Figure 1. It will be seen that the maximum number of dust-particles in the air (both Owen dust and Aitken nuclei) is found on mornings in winter; one reason for this appears to be that the dust-particles, which were in the inversion-layer during night, begin to settle down just about this time as the inversion of temperature disappears. At this time of the year, the small ions are a mini-

[2]Terr. Mag., 19, 205-218 (1914).

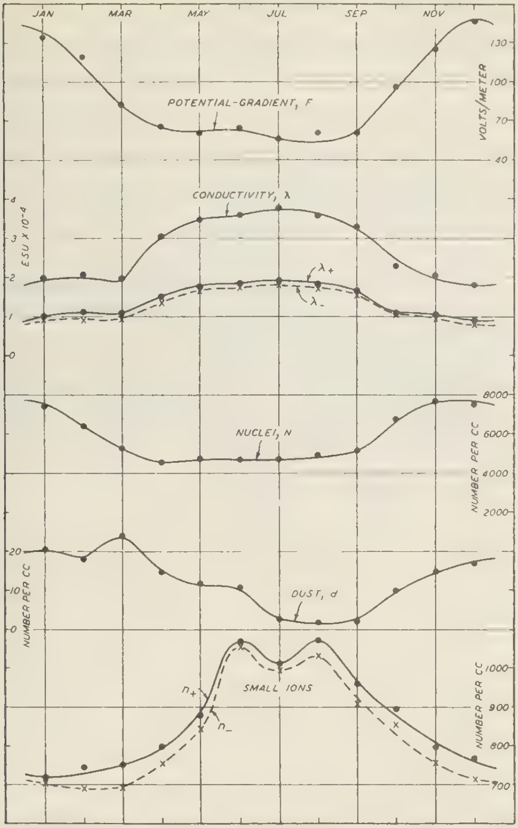

FIG. 1—AVERAGE MONTHLY VALUES OF ATMOSPHERIC-ELECTRIC ELEMENTS AT 10 HOURS, INDIAN STANDARD TIME, AT POONA, INDIA (ALL DATA FOR 1935-1937 EXCEPT FOR POTENTIAL-GRADIENT WHICH ARE FOR SEPTEMBER 1930 TO NOVEMBER 1937)

mum and conductivity is the lowest. As summer approaches, dust-particles in the morning air begin to decrease and attain the minimum value during the monsoon. During monsoon when the air is in a comparatively purer state, the largest number of small ions is found and the conductivity is consequently a maximum. The Earth's field shows almost an inverse variation to the conductivity of the air. It shows a well-defined maximum in winter[3]; this result agrees with the general rule that in the Northern Hemisphere the potential-gradient attains the maximum in winter. Inasmuch as the atmospheric pollution may be regarded as due mainly to Aitken nuclei, it is interesting to note the close similarity[4] of the potential-gradient curve to the graph of nuclei;

[3]For the form of the potential-gradient curve obtained elsewhere in India, see that for Simla given by Simpson in Mem. India Met. Dept., **21**, part 6 (1913).

[4]F. J. W. Whipple, Q. J. R. Met. Soc., **55**, 351-361 (1929).

an increase in the potential-gradient shows a corresponding increase in the number of nuclei per cc of air.

From the monthly values in Table 1, annual averages[5] have been obtained with a view to show the order of their magnitude. These are given in Table 2 together with the factors, q_n, q_λ, and others. The value

Table 2—*Annual averages atmospheric-electric observations at 10 hours, Indian standard time, at Poona*

Potential-gradient, F, volt/meter	89.7	Small ions per cc, n_+	869
Total conductivity, λ, esu $\times 10^{-4}$	2.72	n_-	833
$F_{max}/F_{average}$	1.66	Aitken nuclei per cc, N	5840
$\lambda_{max}/\lambda_{average}$	1.39	Coarse dust-particles per cc, d	13
q_λ and q_n	1.04	$N_{max}/N_{average}$	1.30

1.04 for the factor q_n, shows that at a height of about 46 feet above ground, small ions of opposite polarity exist almost in equal proportion.

[5]For strictly correct values monthly means based on equal number of observations should be considered.

Meteorological Office,
Poona 5, India, February 3, 1938

TEMPERATURE-COMPENSATION OF THE UNIFILAR BY MEANS OF THERMALLOY

By B. M. Janowsky

(1) *Theoretical considerations* The equation of equilibrium of an unifilar, that is, of a magnet suspended by an elastic fiber and being under the action of the horizontal component H of the magnetic field of the Earth has the form

$$MH \sin \theta = C\phi \tag{1}$$

where M is the magnetic moment of the magnet, θ is the angle between the magnetic axis of the magnet and the magnetic meridian, ϕ is the angle of torsion of the suspension-fiber and C is the coefficient of torsion of the fiber.

As the temperature changes, the magnetic moment of the magnet and the coefficient of torsion of the fiber are changing, owing to which the equilibrium is disturbed and the magnet is deflected by a certain angle $\triangle\theta$ from its position of equilibrium. In order to determine the angle $\triangle\theta$ it is sufficient to differentiate equation (1), and we obtain

$$MH \cos \theta \triangle\theta + H \sin \theta (\mathrm{d}M/\mathrm{d}t)\triangle t = -C\triangle\theta + \phi(\mathrm{d}C/\mathrm{d}t)\triangle t$$

Hence, substituting the angle ϕ from equation (1), we have

$$\triangle\theta = MH \sin \theta \left[\frac{1}{C}\frac{\mathrm{d}C}{\mathrm{d}t} - \frac{1}{M}\frac{\mathrm{d}M}{\mathrm{d}t} \right] \triangle t/(MH \cos \theta + C)$$

For the scale-reading $\triangle n$ at the mirror

$$\triangle\theta = \triangle n/2R$$

where R is the distance of the magnet's mirror from the scale. Consequently

$$\triangle n = [2RM \sin \theta/(MH \cos \theta + C)]H \left[\frac{1}{C}\frac{\mathrm{d}C}{\mathrm{d}t} - \frac{1}{M}\frac{\mathrm{d}M}{\mathrm{d}t} \right] \triangle t$$

The value $[2RM \sin \theta/(MH \cos \theta + C)]$ represents the sensitivity of the unifilar, that is, the number of divisions by which the unifilar deflects under the action of a magnetic field of the intensity equal to unity. Designating it as $1/\epsilon_H$, where ϵ_H is the scale-value of the unifilar, we obtain

$$\triangle n = (H/\epsilon_H) \left[\frac{1}{C}\frac{\mathrm{d}C}{\mathrm{d}t} - \frac{1}{M}\frac{\mathrm{d}M}{\mathrm{d}t} \right] \triangle t \tag{2}$$

In order to make the deflections $\triangle n$ of the unifilar independent of temperature, it is necessary that the coefficient of $\triangle t$ for the right-hand side of equation (2) be equal to zero. This is possible only in the case when the term in brackets is equal to zero. For an ordinary magnet this may not be attained, as the value $(1/M)(\mathrm{d}M/\mathrm{d}t)$ representing the temperature-coefficient of the magnet is always negative. Thus the temperature-compensation of an unifilar is possible only through supplementary

arrangements either in form of additional magnets or in form of mechanical devices producing an auxiliary turning moment, varying with temperature.

Such a supplementary arrangement was effected for temperature-compensation by a plate of the new ferro-magetic alloy "thermalloy" or "calmalloy." This plate is laid directly upon the magnet and is made a part of it. Under the action of the magnetic field of the magnet which has an opposite direction to its magnetic moment, the plate is magnetized and acquires a magnetic moment opposite to that of the magnet. Thus, the total magnetic moment of the magnet, M, will represent in this case the difference

$$M = M_0 - M_1 \tag{3}$$

where M_0 is the magnetic moment of the magnet and M_1 is the magnetic moment of the plate.

The alloys thermalloy and calmalloy have such a property that their magnetic susceptibilities k decrease with the increase of temperature and nearly follow a rectilinear law; the Curie point, at which $k=0$, is near 100°C. Therefore, with the rise of temperature the magnetic moments M_0 and M_1 will be decreasing, and the total magnetic moment M under some conditions can either remain constant or change in either sense.

By introducing the value of M from equation (3) in equation (2) we obtain.

$$\triangle n = (H/\epsilon_H) \left[\frac{1}{C}\frac{\mathrm{d}C}{\mathrm{d}t} - \frac{1}{M}\frac{\mathrm{d}M_0}{\mathrm{d}t} + \frac{1}{M}\frac{\mathrm{d}M_1}{\mathrm{d}t} \right] \triangle t$$

The condition for temperature-compensation will be

$$\frac{1}{C}\frac{\mathrm{d}C}{\mathrm{d}t} - \frac{1}{M}\frac{\mathrm{d}M_0}{\mathrm{d}t} + \frac{1}{M}\frac{\mathrm{d}M_1}{\mathrm{d}t} = 0 \tag{4}$$

The term $(1/C)(\mathrm{d}C/\mathrm{d}t)$ represents the temperature-coefficient of the fiber, which we shall designate by β; $(\mathrm{d}M_0/\mathrm{d}t)$ is nothing other than the temperature-coefficient of the magnet, multiplied by the magnetic moment, that is

$$(\mathrm{d}M_0/\mathrm{d}t) = -M_0 q$$

According to equation (4) we may write

$$\beta + q(M_0/M) + (1/M)(\mathrm{d}M_1/\mathrm{d}t) = 0$$

or, since (M_0/M) differs little from unity

$$\beta + q + (1/M)(\mathrm{d}M_1/\mathrm{d}t) = 0 \tag{5}$$

The value of the magnetic moment M_1 may be expressed as

$$M_1 = J_1 v = k\, H_d v$$

where J_1 is the mean intensity of magnetization of the plate, v is the volume of the plate, H_d is the mean intensity of the field acting on the plate and produced by the magnet. If the thickness of the plate is not great, the value H_d for a first approximation may be assumed to be

$$H_d = NJ_0 \tag{6}$$

where N is the coefficient of demagnetization of the magnet.

Accordingly J_0 is the intensity of magnetization of the magnet

$$M_1 = kNJ_0v$$

By differentiating this term we have

$$\frac{\mathrm{d}M_1}{\mathrm{d}t} = NJ_0v(\mathrm{d}k/\mathrm{d}t) + kNv(\mathrm{d}J_0/\mathrm{d}t)$$

or, as $J_0 = (M_0/v_0)$ where v_0 is the volume of the magnet

$$(\mathrm{d}M_1/\mathrm{d}t) = N(v/v_0)[M_0(\mathrm{d}k/\mathrm{d}t) + k(\mathrm{d}M_0/\mathrm{d}t)]$$

The value $(dk/\mathrm{d}t)$ represents the change of susceptibility of calmalloy for a change of temperature of 1° and has a negative value, because k decreases with the rise of temperature. Thus, in designating

$$(\mathrm{d}k/\mathrm{d}t) = -\alpha$$

and substituting

$$(\mathrm{d}M_0/\mathrm{d}t) = -M_0q$$

we have

$$(\mathrm{d}M_1/\mathrm{d}t) = -N(v/v_0)M_0(\alpha + kq) \tag{7}$$

The value kq is small compared with α and consequently may be neglected. Introducing in such case the obtained term for $(\mathrm{d}M_1/\mathrm{d}t)$ in equation (5) and writing $M_0/M_1 = 1$ we have

$$\beta + q - \alpha N(v/v_0) = 0 \tag{8}$$

All the values constituting this equation except v—the volume of the plate—are constant. Accordingly, in varying the volume of the plate it is always possible to have the equation (7) satisfied, that is, the temperature-compensation may be realized if

$$v = [(\beta + \mu)/N\alpha]v_0 \tag{9}$$

It is necessary to take into consideration that the value of the coefficient of demagnetization N in equation (7), assumed as a mean on the whole extent of the magnet, remains constant only for the case when the length of the calmalloy plate remains unchanged. Therefore, for a given magnet the volume of a calmalloy plate for temperature-compensation may be different depending on its length.

(2) *Properties of the thermomagnetic alloy calmalloy*—The principal property of calmalloy is that its induction and permeability for any given outer field decrease rapidly as the temperature increases, falling to zero in the case of calmalloy *A* at about 140°C (Curie point).

Owing to these properties this alloy has been much used for some time past in the electrotechnical industry for temperature-compensation of electrical measuring instruments. The principle of this compensation is the same as described above, but rather simpler in theoretical as well as in practical respects, because it is not the change in magnetic moment which is to be compensated but the magnetic field and because the magnets have not a rectilinear form, but the form of a horseshoe.

The alloy prepared in Laboratory of the All-Union Institute of Metrology in Leningrad and taken for the investigation had the following composition: Nickel, 55.8 per cent; copper, 24.9 per cent; iron, 15.5 per cent; silicon, 1.8 per cent; manganese, 1.2 per cent; admxitures,

0.8 per cent. The magnetic properties of this calmalloy at different temperatures have been tested on an astatic magnetometer of the Magnetic Laboratory of the Institute of Metrology. The specimen on test had the form of a rectangular bar of section 1.12 by 1.12 cm and 10 cm in length. The results of the tests are represented in Figure 1, which shows the dependence of the intensity of the plate J, susceptibility k, and the coefficient $\alpha = (\mathrm{d}k/\mathrm{d}t)$ on temperature at three values of the magnetizing field, the values J and k being referred to the test-specimen.

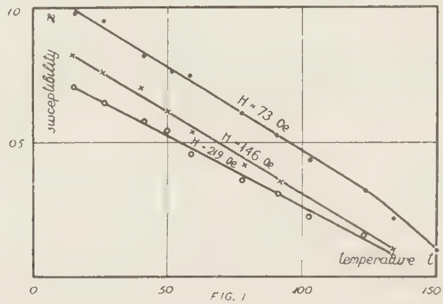

FIG. 1

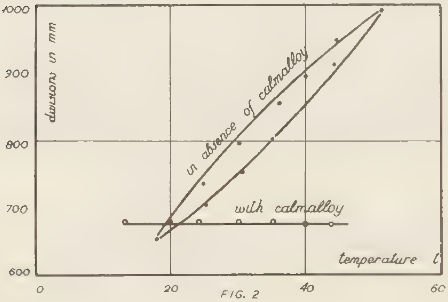

FIG. 2

As may be seen, the curves in the region of temperatures from 15° to 60° are of rectilinear character.

§ 3. *Experimental test of the method of temperature-compensation* In order to test the method of compensation by means of calmalloy a magnet of nickel-aluminium-steel of the dimensions 2.5 by 2.5 by 20 mm was used. Its temperature-coefficient was determined by the magnetometric method and proved to be $q = 464 \times 10^{-6}$.

The investigation of the compensation for temperature was made on a magnetometer which could be brought to any temperature from 15° to 60°C and above. The magnet to be tested was the magnet of this magnetometer; it was suspended on a quartz fiber. The observations were made by visual readings with a telescope and scale. The magnet was set by twisting the fiber in the direction perpendicular to the magnetic meridian, and the scale-value of such a magnetometer was determined by means of Helmholtz's coils.

The results of the observations of the magnetometer for a variety of

temperatures in absence of calmalloy and with calmalloy are represented in Figure 2. The divisions of the magnetometer readings in mm are plotted as ordinates and the temperatures as abscissae. The observations were made with the scale-value $\epsilon_H = 1.27$ per mm.

The dimensions of the calmalloy plate which compensated the temperature-coefficient proved to be: Height a, 0.089 cm; width b, 0.193 cm; length l, 1.568 cm; and volume v, 0.0270 cc.

The curves show that the compensation with a plate of calmalloy is almost complete; but that it requires an experimental choice of appropriate dimensions of the plate. This is obtained by constantly reducing the dimensions of the plate and observing the temperature-coefficient. The data of the curves make it possible to determine the temperature-coefficient of the magnetometer $q_1 = q + \beta$ according to formula

$$q_1 = [(n_{t0} - n_t)/(t_0 - t)]\ \epsilon_H/H$$

where n_{t0} and n_t are readings of the magnetometer at temperatures t_0 and t. The resulting mean value obtained is $q_1 = 851 \times 10^{-6}$. The value q being known, we determine the temperature-coefficient of the fiber to be $\beta = 464 \times 10^{-6}$.

Comparing the experimental results with the theoretical data we observe a certain divergence. According to formula (9) the volume of the calmalloy plate ought to be $v = 0.040$ cc (the coefficient of demagnetization N for the given dimensions of the magnet is 0.412). Whereas the experiment gives $v = 0.027$ cc, which is half the former value. This divergence is explained by the approximate result from formula (9) and as previously stated, the coefficient of demagnetization assumed for the given dimensions of the magnet depends also on the form and dimensions of the calmalloy plate. Despite this divergence the theoretical formula does give an approximate value of the plate's volume from which we may proceed in our experimental tests.

Summary—The method of temperature-compensation proposed by the author makes it possible to reduce the temperature-coefficient of the magnetometer to zero; further it has advantages over the existing methods—magnetic, optical, and mechanical—because it does not require supplementary arrangements in the magnetometer, thus simplifying in a considerable degree the construction of the magnetometer. The second advantage of the new method is that the compensation does not depend on the value of the magnetic field in which the magnetometer is placed.

Central Magnetic Observatory,
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NOTES

(See also pages 154, 161, and 191)

15. *Magnetic work in the Far East*—W. C. Parkinson of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, who has been engaged in magnetic field-work in Australasia, arrived at Singapore, February 28, 1938, preparatory to occupying a series of stations in Malaya, Indo-China, Siam, and certain portions of the Dutch East Indies. During the month of March he occupied ten stations as follows: Singapore, Malacca, and Penang, Straits Settlements; Kuala Lumpur and Ipoh, Federated Malay States; Alor Star, Malaya; Tung Song, Chumphon, Hua Hin, and Bangkok, Siam. The object of this expedition is to secure data for use in studies of the secular variation. On conclusion of this field-work he plans to compare his instruments with the standards and field-instruments used by the Batavia Observatory thus tying in their field-work with that of the Carnegie Institution of Washington.

16. *Secular-variation work in South Africa* Under the auspices of the Magnetic Observatory of the University of Cape Town, secular-variation work has been started in South Africa. At Buffalo Hill, where the previous station could not be reoccupied on account of drifting sand, a new station was established and a pier about four feet high, made of carefully selected material, was erected which will serve for exact reoccupations in the future.

17. *Magnetic work in Norway*—Work on a magnetic survey of Norway will be begun this summer under the direction of the Magnetic Bureau of the Geophysical Institute at Bergen.

18. *Missouri Academy of Science*—A Missouri Academy of Science was organized and held its first annual meeting on April 21, 22, and 23, 1938. Prof. H. R. Grummann, of Washington University, Saint Louis, presented a paper before a joint session of the divisions of Geography, Geology, and Geophysics on the "Magnetic-survey work of the Carnegie Institution of Washington."

19. *Swedish magnetic-survey vessel*—The Hydrographic Service of Sweden is building a small vessel for magnetic measurements in the waters surrounding Sweden. This boat will be 17.0 meters in length and, although not wholly non-magnetic, it is hoped that the small quantity of magnetic material will not prevent keeping the deviations small, or at least constant enough, for satisfactory measurements.

The first expedition of the new boat will be begun early this summer and measurements of declination, horizontal intensity, and vertical intensity will be made in the southern portions of the waters surrounding Sweden. During 1939 and 1940, the Hydrographic Service of Sweden and the Finnish Meteorological Central Office are planning to cooperate in carrying out magnetic measurements in the Gulf of Bothnia.

Tests will be made for determining the horizontal intensity by means of the double compass which was used during the arctic trip of the *Graf Zeppelin* in 1931, and which has been loaned for the purpose by the Carnegie Institution of Washington. If the trials prove satisfactory, a double compass will be acquired for the work in prospect.

THE ELECTRIC CHARACTERIZATION OF DAYS AT THE HUANCAYO MAGNETIC OBSERVATORY FOR THE TWELVE YEARS, 1925-1936

By O. W. Torreson

Observations of the atmospheric potential-gradient were begun by the Carnegie Institution of Washington at the Huancayo Magnetic Observatory, in Peru, in 1924. A photographically-recording apparatus was installed at that time and has been in practically continuous operation up to the present. The data thus accumulated are now being tabulated for publication and will appear shortly, together with complete descriptions of the apparatus, its location, and particulars of the surrounding countryside.

At the inauguration of the observing-program it was decided that the electric characterization of days as used by the British Meteorological Office at Kew Observatory should be adopted. This system has recently been described in detail by F. J. W. Whipple[1] and need be mentioned only briefly here. There are three character-figures, 0, 1, and 2. "0" denotes the absence of negative potential in any 24-hour period beginning at midnight, "1" indicates the existence of negative potential at one or more times during the 24-hour period but with a total duration of less than three hours, and "2" indicates the existence of negative potential for a total duration of three hours or more.

Using these definitions as a basis it has been possible to assign character-figures to all but 111 of the 4,383 days of the twelve-year period under discussion, each day beginning at 0^h, 75th west meridian time. On the 111 days omitted (57 of these were in the first three years and 54 in the last nine) the recording instrument either was defective or was not being operated. Table 1 gives the summary of the assigned character-figures, where it is seen that about 100 days each year are, on the average, of character 2, 200 days of character 1, and 50 days of character 0. About ten days each year could not be characterized.

In Table 2 are given rainfall-data for the twelve-year period. All rainfall-data were obtained with a United States Weather Bureau Pattern rain- and snow-gage. In this gage the rain is caught in a brass-rimmed collector eight inches in diameter from which it is funnelled down into the measuring-tube which is 2.53 inches in diameter and 20 inches high. A wooden stick, graduated to measure rainfall to hundredths of inches, is inserted into the measuring tube when a measurement of the rainfall is desired. At the Huancayo Magnetic Observatory the rainfall was measured each morning at 8 o'clock. The monthly data in Table 2 represent the sums of the daily measurements for each month, and no days were omitted in the twelve-year period.

At Huancayo, located at altitude 11,000 feet, latitude 12° 03′ south, and longitude 75° 20′ west, snow never appears, but there are occasional hailstorms. There are only two seasons—wet and dry—and from Table 2 it may be seen that the dry season is confined largely to the four months from May to August. Actually, after first-hand experience with the locality, one recognizes that the dry season generally includes the last half of April and the first half of September, so that the dry season is about five months in length and the wet season about seven months.

[1]Terr. Mag., 42, 129-136 (1937).

January to March are the most disturbed months meteorologically, with some rainfall nearly every day.

These conditions are reflected in the character-figures in Table 1

TABLE 1—*Distribution of days according to duration of negative potential-gradient, Huancayo Magnetic Observatory, 1925-36*

Month	Year												Total	Average
	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936		
	"0"-Days—No negative potential-gradient													
Jan.	0	0	2	5	0	2	1	1	0	1	1	0	13	1
Feb.	1	1	0	1	2	0	2	3	0	1	0	1	12	1
Mar.	0	1	1	2	1	0	5	0	0	1	0	9	20	2
Apr.	1	4	8	1	7	5	0	3	5	6	7	4	51	4
May	11	10	10	9	4	8	10	10	8	17	7	6	110	9
June	18	16	7	4	8	16	5	8	8	15	8	4	117	10
July	16	20	12	11	6	13	7	7	4	14	7	7	124	10
Aug.	13	10	8	9	3	13	2	1	4	7	6	5	81	7
Sep.	12	4	2	5	3	4	1	2	4	3	5	1	46	4
Oct.	5	5	4	0	3	4	2	0	4	4	2	3	36	3
Nov.	1	3	1	3	2	1	0	0	2	2	2	4	21	2
Dec.	2	5	3	2	0	0	0	1	0	1	1	3	18	1
Sum	80	79	58	52	39	66	35	36	39	72	46	47	649	54
	"1"-days—Less than three hours of negative potential-gradient													
Jan.	9	14	13	8	17	8	8	15	9	8	8	8	125	10
Feb.	8	14	13	14	8	8	9	9	9	6	8	16	122	10
Mar.	5	16	17	10	9	6	21	11	4	6	5	10	120	10
Apr.	16	15	15	17	17	10	12	20	15	18	17	23	195	16
May	15	9	15	20	25	12	19	19	21	11	22	21	209	17
June	11	10	21	24	19	10	25	20	20	13	21	26	220	18
July	13	8	16	18	25	15	24	24	25	17	23	21	229	19
Aug.	16	14	18	17	22	11	29	30	27	23	25	22	254	21
Sep.	18	17	19	17	20	13	29	24	22	18	13	23	233	19
Oct.	20	24	21	13	10	9	25	20	11	16	20	18	207	17
Nov.	13	15	14	11	21	17	24	16	23	19	19	8	200	17
Dec.	20	14	20	14	16	22	11	17	15	21	10	15	195	16
Sum	164	170	202	183	209	141	236	225	201	176	191	211	2309	190
	"2"-days—More than three hours of negative potential-gradient													
Jan.	20	16	16	17	14	18	22	15	22	22	22	23	227	19
Feb.	18	11	11	14	18	20	15	17	19	21	20	12	196	16
Mar.	18	13	13	19	21	25	5	20	27	24	26	12	223	19
Apr.	13	11	4	11	6	12	15	7	10	6	6	3	104	9
May	2	3	6	2	2	9	0	2	2	3	0	4	35	3
June	1	0	2	2	3	0	0	1	2	2	1	0	14	1
July	1	1	3	2	0	3	0	0	2	0	1	3	16	1
Aug.	2	3	4	5	1	7	0	0	0	1	0	4	27	2
Sep.	0	6	8	8	7	5	0	4	4	8	12	6	68	6
Oct.	5	2	6	18	18	10	3	11	16	11	7	10	117	10
Nov.	11	12	14	16	7	12	6	13	5	9	9	15	129	11
Dec.	9	12	8	15	15	8	20	13	16	9	20	13	158	13
Sum	100	90	95	129	112	129	86	103	125	116	124	105	1314	110

TABLE 2—*Total rainfall in each month and days when some rain fell, Huancayo Magnetic Observatory, 1925–36*

Month	1925		1926		1927		1928		1929		1930	
	Inch	*Days*	*Inch*	*Days*	*Inch*	*Days*	*Inch*	*Days*	*Inch*	*Days*	*Inch*	*Days*
Jan.	4.74	28	3.45	24	3.28	26	4.24	24	2.88	20	6.23	31
Feb.	4.37	24	3.47	22	3.43	24	3.56	23	6.63	26	4.66	26
Mar.	8.41	26	3.19	24	2.96	28	3.87	28	4.77	28	4.86	30
Apr.	3.32	24	4.95	25	0.84	16	1.36	17	1.68	16	2.04	22
May	0.71	14	1.72	15	1.59	15	0.80	6	0.75	7	1.75	20
June	0.05	4	0.10	5	0.42	8	0.23	4	1.22	6	0.17	5
July	0.30	9	0.15	4	0.84	7	0.07	3	0.24	7	1.14	5
Aug.	0.44	10	0.93	10	1.24	10	0.20	6	0.80	11	0.90	11
Sep.	0.77	9	1.99	20	2.19	20	2.07	20	1.36	16	1.37	14
Oct.	2.84	20	0.90	12	1.14	12	2.41	22	3.30	25	2.46	18
Nov.	5.29	20	3.40	23	3.14	19	2.09	19	1.35	17	3.29	20
Dec.	4.52	25	2.74	21	1.44	18	2.60	21	2.00	22	1.81	16
Sums	35.76	213	26.99	205	22.51	203	23.50	193	26.98	201	30.68	218

Month	1931		1932		1933		1934		1935		1936		Averages 1925–36	
	Inch	*Days*	*Inch*	*Days*	*Inch*	*Days*	*Inch*	*Days*	*Inch*	*Days*	*Inch*	*Days*	*Inch*	*Days*
Jan.	3.28	26	4.40	27	6.74	25	5.27	28	7.07	28	7.06	31	4.89	26
Feb.	2.67	20	3.60	26	5.06	26	4.74	27	4.66	28	2.83	24	4.14	25
Mar.	2.77	18	4.30	28	7.96	30	5.07	30	9.15	30	2.24	20	4.96	27
Apr.	2.90	22	1.34	16	1.25	16	0.60	16	1.62	24	1.25	13	1.93	19
May	0.13	5	1.65	16	0.67	7	1.07	9	0.04	8	0.84	17	0.98	12
June	0.07	3	0.19	5	0.48	6	0.90	12	0.42	9	0.01	7	0.35	6
July	0.77	5	0.05	4	0.25	5	0.22	5	0.17	6	0.44	5	0.39	5
Aug.	0.19	5	0.04	5	0.35	12	0.73	12	0.31	4	0.30	5	0.54	8
Sep.	1.40	17	2.64	20	1.22	20	1.52	17	2.23	16	1.74	21	1.71	18
Oct.	2.59	20	2.93	16	3.61	22	2.21	18	2.67	18	2.25	20	2.44	19
Nov.	2.27	15	4.19	19	1.26	13	2.71	23	3.06	19	5.85	25	3.16	19
Dec.	3.81	26	3.10	21	3.48	22	2.87	17	5.16	27	2.17	15	2.97	21
Sums	22.85	182	28.43	203	32.33	204	27.91	214	36.56	217	26.98	203	28.46	205

where days of characters 1 and 2 for January to March number 29, 26, and 29, respectively, and the days of character 2 are far more numerous than those of character 1. Even in these three months the days of negative potential outnumber the days of rainfall, but the difference is small and may be accounted for by the reversal of the normal field by near-by thunder-clouds without any rain falling at the Observatory. In each of the remaining nine months, however, the difference between the days of negative potential and days of rainfall is much greater, and in the three months of June, July, and August, nearly half of the days have negative potential without rainfall.

From observations of staff-members, and from weather-notes, it can be definitely stated that cloudy or overcast skies cause but a small portion, if any, of the days of character 1 without rainfall encountered in the dry season. At that time of year, day after day for extended periods will be cloudless, while on many other days there are scattered bits of cirro-cumulus which may appear and remain for brief intervals.

When the photographic records of potential-gradient are examined, it is found that on many days in each of the dry months, almost always in the afternoon, there are brief excursions of the recording-spot to negative potential, these excursions requiring from a minute or less to perhaps ten minutes to depart from the normal trend of the diurnal curve, become negative, and return again to the normal value. The momentary negative value is never excessive, usually less than 100 volts, and very often the movement of the spot is so rapid that only the turning-point of the excursion is recorded. Thus, what would otherwise have been a day of character 0 becomes a day of character 1 because there is a brief period of negative potential. With the negative excursion so brief, the normal trend of the diurnal curve is usually not significantly affected. At least half of the days of character 1 in the dry months are of this kind and often more than half. Occasional days in other months of the year are also of this character.

An explanation for the brief negative excursions that has suggested itself to observers at the station is based on the presence of small short-lived whirlwinds in the vicinity. These whirlwinds form on the open, rolling plain surrounding the site of the Observatory, move in approximately a straight line but with varying velocity at different points along the track, progress a kilometer or two, and disappear within a few minutes after formation. Nearly always there is a visible dust-cloud accompanying the whirlwind. While it has not been possible to make a systematic study of the time of appearance and number of whirlwinds for comparison with potential-gradient records, it is believed that they, if passing sufficiently near the potential-gradient collector, temporarily affect the space-charge conditions in the vicinity of the collector so as to produce the brief negative potential just described.

Of the approximately 100 days with negative potential but without rainfall in each year, at least half, and perhaps more, can be accounted for by the existence of those brief periods of negative potential which might be caused by the whirlwinds. Whipple, finding many days at Kew with negative potential but without rainfall, points out that one of the defects of the present system of character-figures is that no distinction is made between days when negative gradient is associated with rain and days when some other cause is operating. For Huancayo, many of the days with brief periods of negative potential are still "quiet" days and as such might well have a character-figure indicating that they are suitable for inclusion in monthly means which are taken to find the normal mean diurnal variation. However, while the inclusion of quiet days of character 1 will augment considerably the number of available days for monthly means in the dry months, little material will be added in this way in other months.

Considering days of character 0 in Table 1, from which it is to be expected that quiet days will be obtained for studying normal diurnal variations, it is seen that two-thirds, or 36 days of the average yearly total of 54, are in the four dry months of May to August. If, to the 54-day yearly total, selected quiet days of character 1 are added to bring available days up to, say, 100, the four dry months will have about 70 days, and the remaining eight months only 30 days for study.

From the foregoing considerations it is evident that the Huancayo Magnetic Observatory is favorably situated for the study of the electrical

fields associated with thunder-storms and bad weather. Thus far, the potential-gradient measurements have been made with apparatus of the type and sensitivity suitable for measuring the small gradients of one or two hundred volts per meter, or less, prevailing in fair weather, and for revealing the minor variations in those gradients. The large gradients during bad weather, and the large and rapid variations in them, have not been within the range of the apparatus, but examination of the photographic records of potential-gradient for all the years under discussion shows a wealth of material representative of the moderate gradients of the more distant or less severe periods of thunder-storm, analysis of which it is hoped may soon be undertaken.

For the complete recording of potential-gradients in both good and bad weather it seems necessary that two pieces of apparatus be employed, one insensitive compared with the other. Few atmospheric-electric observatories are so equipped at the present time. Whipple and Scrase began continuous recording with insensitive potential-gradient apparatus at Kew Observatory in 1932[2], and added to their equipment a "point-discharger" apparatus similar to that first used by Wormell[3], for measuring the currents flowing between the air and Earth during thunder-storms. Indications of additional observatories where equipment such as that adopted at Kew might be installed to great advantage, might well be obtained from electric character-figures compiled by those observatories now engaged in potential-gradient measurements.

With such a thought in mind, it would be extremely helpful if every station making observations of atmospheric potential-gradient would assign the Kew character-figures to its data with the idea that, if the character-figures show that bad weather and thunder-storms stand out as important features of the atmospheric-electric conditions at any station, that station would seriously consider ways and means of undertaking intensive study of the electricity of thunder-storms and bad weather. Probably only by such a program can we finally determine the extent to which these phenomena contribute to the maintenance of the negative charge of the Earth.

[2]Geophys. Mem., British Met. Office, 7, No. 68 (1933-36).
[3]Proc. R. Soc., A, **115**, 443 (1927).

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NOTES

(See also pages 148, 166, and 191)

20. *Annual meeting of the Society of Exploration Geophysicists*—The annual meeting of the Society of Exploration Geophysicists was held at New Orleans, Louisiana, March 15-17, 1938. On the program of this meeting were several papers dealing with various aspects of electrical prospecting. At a joint technical session with the American Association of Petroleum Geologists, the following two papers, of interest to both geologists and geophysicists, were presented: "Discoveries" by Alexander Deussen, and "Review of the relation between physics and geology" by J. C. Karcher.

21. *International Congress of Cosmobiology* The first meeting of the International Congress of Cosmobiology will be held on the "Côte d'Azur," France, June 2 to 6, 1938. This Congress is formed by the Medical Society of Climatology and Hygiene of the Mediterranean Littoral, with the cooperation of the International Association for the Study of Solar, Terrestrial, and Cosmical Radiations, under the honorary presidencies of Professor d'Arsonval, for radiology, M. A. Lumière, for biology, and M. H. Deslandres, for astronomy. The meetings will be held at Nice, Monaco, and Menton. Several excursions will be made during the Congress, and following the Congress there will be a more extended excursion, June 7 to 11, to Corsica.

The studies of the Congress fall into six groups, of which the following bear on subjects of interest to readers of this JOURNAL: Astronomy and astrophysics solar corona, periods of solar disturbances (storms, eruptions, prominences, spots) and their terrestrial relationships; solar spectrum—ultra-violet and infra-red, biological, pathological, and therapeutical effects, and other radiations from the Sun; electrical conductivity and ionization of the air -possible action on human beings, radioactivity of rocks and the soil, etc., thermal and mineral waters; cosmic rays--upper atmosphere and terrestrial magnetism; meteorology in its relations with morbid manifestations on the one hand, and with atmospheric electricity and cosmical influences on the other.

22. *Notes from United States Coast and Geodetic Survey*—On March 26, 1938, the magnetic character-number assignments for the Los Angeles Observatory, operated by the Coast and Geodetic Survey during the period 1882-90, were forwarded to Dr. Van Dijk. The character-numbers for the San Antonio Observatory, Texas, for the period 1890-95 were likewise forwarded in February, 1938.

An auxiliary absolute observatory is being constructed at the Tucson Magnetic Observatory to facilitate comparison-observations of field-instruments and of intercomparison of standards.

23. *Corrigenda*—In the issue of March 1938 corrections should be made as follows: Page 7, first foot-note, read "(New Series)" instead of "(News Series)"; page 8, following second paragraph, add foot-note "*J. Clay and E. M. Bruins, Physica, **5**, 11 (1938), found similar results in Amsterdam."; page 8, last line before sentence beginning "The third" insert "Correlation-coefficient of daily mean values of J at these two stations, calculated from four months, was $+0.848 \pm 0.036$."; page 10, at end of second paragraph add "($1 mJ = 0.001 J$)"; page 10, second last line of third paragraph, read "same order of magnitude" instead of "same magnitude"; page 13, twelfth line of third paragraph, read "as is otherwise" instead of "as opposed to."

GEOPHYSICAL LUNAR ALMANAC*

By J. Bartels and G. Fanselau

Summary—The astronomical year-books furnish complete data for the motion of the apparent Moon from day to day. Those tables, which so far have had no counterpart for the *mean* Moon, are frequently, because of their convenience, used as a basis for geophysical computations on lunar effects. Thereby, however, the connection is lost with the harmonic analysis of the tidal forces, which is based on the mean Moon; furthermore, the unequal length of the apparent lunar day is troublesome in the computations. Adolf Schmidt has introduced magnitudes μ, $(\pi+\mu)$, and $(\rho+\mu)$, which, in suitable form, indicate the phase of the mean Moon and its distance from mean perigee and from the mean ascending node of the Moon's orbit. Tables are given here for these magnitudes, from which they can be read easily for each day of the years 1850 to 1975. The differences between the motions of the apparent Moon and the mean Moon are illustrated by some extreme cases.

§ 1. *Description of the tables for practical use*—For the investigation of geophysical effects of the Moon, especially of the tides, procedures and tables are available since long, as well for the harmonic analysis of the tidal forces themselves as for the analysis of the observations at tidal gages and the synthesis for the prediction of ocean tides [1-4]. The observations of the variations of the plumb-line, with the horizontal pendulum, are reduced similarly [5]. Less uniformity exists in the procedures used in the reduction of other lunar influences, for example, on atmospheric pressure or terrestrial magnetism. Here, in contrast to tidal theory, the reduction is often based on the movement of the apparent Moon instead of the mean Moon; from the astronomical year-books, the times for the Moon's transit and for its declination are taken and its distance from the Earth is judged by the Moon's diameter. Thereby, the reduction of long series (necessary in the case of tides in the atmosphere and the ionosphere) seems simplified because the values for the apparent Moon are readily available for each day; this convenience is, however, paid for too dearly because the harmonic analysis of the tidal potential is then no longer applicable, and the tidal forces must be estimated by more or less rough methods [12]. For this reason the Tables given supply the values for the movements of the mean Moon in such a form that they can be read easily for each day of the years 1850 to 1975.

For the derivation of the lunar influence on the magnetic elements in Potsdam and Seddin, Adolf Schmidt [6, 7] has introduced magnitudes which have proved useful also in other computations [8, 9]. Their definition is taken here without serious change. In analogy to mean *solar* local time t, a mean *lunar* local time τ is introduced; it is determined by the motion of the mean Moon, which is imagined to revolve uniformly. Just as t is counted in 24 solar hours from midnight to midnight, $\tau=0$ for the lower transit of the mean Moon, increasing by 24 lunar hours up to the next lower transit. A mean lunar day equals 1.03505 solar days, or 24 hours 50.47 minutes. The difference between t and τ determines the Moon's phases in the *synodic* month, from a new Moon to the next one; the same values of $(\tau-t)$ are repeated after 29.5306 mean solar days. The phase is given for each day by the value μ, the hour-angle (counted positive toward west from the *upper* transit) of the mean Moon at the time of Greenwich mean noon; μ is given in hours, not in degrees ($15°=1$ hour). Expressed differently μ is the number of lunar hours, which, at the time of mean noon at Greenwich, have passed since the last upper transit of the Moon, or $(\mu\pm12)$ is the lunar time of mean noon at Greenwich.

From one day to the next μ decreases by 0.81272; and in the course of a synodic month μ *decreases* from 24 to 0. $\mu=0$, is New Moon; $\mu=18$,

*Translation of the first part explaining the tables, from Zs. Geophysik, 13, 311-328 (1937); the second part and the tables to be found there

is first quarter; $\mu=12$, is Full Moon; $\mu=6$ is last quarter for the mean Moon [for theoretical purposes, it may be useful sometimes to use the *increasing* values $\nu=(24-\mu)$ instead of μ].

In Table 1, μ is given for the first day of each month, 1850 to 1975; for the other days of each month ($n=2, 3, 4 \ldots$), the changes -0.81272 $(n-1)$ are given, to two decimals, in Table 4 for interpolation. If long series are reduced, it is sufficient to combine the days in groups with values μ rounded off to integers; for this purpose, Table 5 gives figures which have to be added to the figure *before* the decimal point (in Table 1 for the first of the month) in order to obtain the value μ, rounded off to integers, for each day of the month. If μ becomes negative, 24 must be added, and if μ becomes larger than 24, 24 must be subtracted.

Example (*a*) *for May 1932*—From Table 1, for May 1, $\mu=3.25$; the μ-figures, to two decimals, are found from Table 4, for example, for May 15, $\mu=3.25-11.38\ (+24.00)=15.87$, and for May 16, $\mu=3.25+11.81=15.06$. The μ-figures, rounded off to integers, are obtained from Table 5 (line for the decimals 0.25 to 0.29 of the μ for the first of the month), for example, for May 15 $[3-11\ (+24)]=16$, and for May 16, $3+12=15$.

Example (*b*) *for June 1934*—For June 1, $\mu=8.77$; from Table 5 (line for the decimals 0.75 to 0.79) the values μ rounded off to integers, for the whole month of June are as follows: 9, 8, 7, 6, 6; 5, 4, 3, 2, 1; 1, 0, 23, 22, 21; 21, 20, 19, 18, 17; 17, 16, 15, 14, 13; 12, 12, 11, 10, 9.

The distance from the Earth and the declination of the Moon are determined by its angular distances (increasing uniformly) π from mean perigee and ρ from the mean ascending node—π and ρ indicate how far the Moon is towards the *east* of perigee or node. π completes a revolution in an anomalistic month (from one perigee to the next one) in 27.5546 days; ρ completes a revolution in a draconitic month (between two successive passages through the mean ascending node) in 27.2122 days. However, the values $(\pi+\mu)$ (hour-angle of the perigee) and $(\rho+\mu)$ (hour-angle of the ascending node) do not complete a revolution before about one year; within a month, they change therefore so little, that, in actual computation, several successive days can be combined as belonging to a mean value $(\pi+\mu)$ or $(\rho+\mu)$. The flattening caused by this smoothing must be taken into account in the final reductions. In Tables 2 and 3, the values $(\pi+\mu)$ and $(\rho+\mu)$ are given for Greenwich noon of the first of each month, and by means of Table 4, the accurate values can be obtained for each day of the month—unless it is preferred to combine groups of days with nearly equal values of $(\pi+\mu)$ and $(\rho+\mu)$ (for example, months or double-months [7]).

The accurate definitions, with the mean longitudes s of the Moon, h of the Sun, p of the perigee, N of the ascending node, all expressed in the unit 1 hour$=15°$ are: $\mu=(h-s)$; $\pi=(s-p)$, $(\pi+\mu)=(h-p)$; $\rho=(s-N)$, $(\rho+\mu)=(h-N)$. The local mean lunar time τ, the local mean solar time t of a locality in geographical longitude λ east (in hours), and the mean lunar time τ_0 and mean solar time t_0 at Greenwich are connected as follows: $\tau=(t+\mu)$, $t=(t_0+\lambda)$, $\tau=(\tau_0+\lambda)$.

Intervals of 24 solar hours, limited by Greenwich midnight, are characterized by the values μ, $(\pi+\mu)$, and $(\rho+\mu)$, valid for Greenwich noon of the particular day (Tables 1 to 5). Since the international magnetic character-figures are given for such intervals, these intervals are sometimes used also for reducing magnetic observations at stations in other geographic longitudes. Then, of course, the same values as for Greenwich are valid for the centers of these intervals. If, however, days are used which are limited by local mean midnight, Greenwich

noon is eccentric in this interval. For the instant of local mean noon, $\mu(\lambda)$ is obtained from $\mu(0)$ (for Greenwich noon of the same date) according to the formula

$$\mu(\lambda)=\mu(0)+0.03386\lambda=\mu(0)+\lambda/29.5306$$

Here λ is reckoned in hours (degrees divided by 15), and as positive east of Greenwich up to the date-line, and as negative west of Greenwich. $(\pi+\mu)$ and $(\rho+\mu)$ change much less than μ if local noon is used for Greenwich noon, namely

$$\pi(\lambda)+\mu(\lambda)=\pi(0)+\mu(0)-0.00243\lambda$$
$$\rho(\lambda)+\mu(\lambda)=\rho(0)+\mu(0)-0.00289\lambda$$

Of course, it is not recommended to correct the value μ separately for each local day, but to carry on throughout with the μ-figures of our Tables. The transition to the local day is then effected in the final stage by a corresponding constant change in the phase-angle of the resultant sine-wave, because

$$\tau=t+\mu=t+\mu(0)+[\mu(\lambda)-\mu(0)]$$
$$\sin\,(2\tau+\epsilon_2)=\sin\,\{2[t+\mu(0)]+\epsilon_2+2[\mu(\lambda)-\mu(0)]\}$$

The phase-angle, obtained by using the $\mu(0)$ valid for Greenwich, must therefore be *reduced* by $2[\mu(\lambda)-\mu(0)]=2\lambda/29.53$, in order to find the phase-angle ϵ_2 corresponding to the local day. By this correction, the rough phase-angle is diminished for eastern stations and is increased for western stations.

If Greenwich days are used for stations in other longitudes, a peculiar difficulty arises in the case of terrestrial-magnetic variations [9]. Since these are much stronger during the hours of daylight than during those of night, but those of daylight are eccentric with respect to the Greenwich day, it may be more adequate to characterize the interval not by the μ-figure for the middle of the interval (Greenwich noon), but by a μ-figure that corresponds better to the local hours of daylight within this interval.

Extensive tables giving μ for each day, 1850 to 1975, have been prepared and will be published by the Geophysikalisches Institut, Potsdam.

§2. *Computation of the Tables*—The Tables were computed on the basis of the astronomical elements given in Brown's Tables of the Moon [11].

Adolf Schmidt had applied to his μ-figures the small correction $(\xi-\nu)$, in accordance with the tidal theories of Darwin and Börgen, who represented the influence of the slow revolution (once in 18.6 years) of the node of the Moon's orbit not by independent terms, but by changes, from year to year, in the amplitudes and phases of the other terms. This correction $(\xi-\nu)$ changes μ by at most 0.07. In Tables 1 to 5, this correction is *not* applied; these Tables therefore are consistent with Doodson's tidal analysis [3, 4] referring to the mean Moon throughout.

3. *The difference between apparent and mean lunar time*—The difference between apparent and mean *solar* time is well known as the equation of time; however, it seems justified to discuss the difference between apparent and mean lunar time in a paper which is meant to show the advantages of referring to the mean Moon. The formulae for the motion of the apparent Moon enable one to estimate the order of magnitude of these differences. Looking through the "Berliner Astronomisches Jahrbuch", the most striking changes were found in the

duration of the apparent lunar day—the time-interval from one transit to the next. On December 22 to 23, 1893, for instance, the length of the apparent lunar day was 25 hours 8.6 minutes, but on August 18 to 19, 1913, it was only 24 hours 38.7 minutes, nearly half an hour less. The semi-diameter of the Moon's disk was 16′ 47″.4 in the first case and 14′ 43″.0 in the second case. (In comparison, the duration of the apparent solar day never deviates from that of the mean solar day by more than half a minute of time).

On January 13 to 15, 1930, the upper transits of the Moon followed each other after an interval of 25 hours 7.3 minutes; the semi-diameter reached 16′ 47″.4, as in the former example. About half a month before or after such day on which the Moon approaches the Earth so closely, the greatest differences between apparent and mean lunar time are to be expected. In fact the differences between the Moon's apparent longitude s_1 and her mean longitude s were $(s_1-s)=-7^\circ.86$ on January 9 and $+7^\circ.84$ on January 21, Greenwich midnight. This means that on January 9 the apparent Moon culminated more than half an hour *before* the mean Moon, but, because of the great proximity to the Earth, speeded up its orbital motion and, on January 21, culminated half an hour *after* the mean Moon. With such great irregularities, it is clear that the uniformly progressing mean Moon facilitates the computations; the influence of the complicated motions of the apparent Moon can then easily be estimated from the harmonic analysis of the tidal forces.

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AN ELECTROMAGNETIC METHOD OF DETERMINING INDUCTION-COEFFICIENTS OF MAGNETOMETER-MAGNETS

By J. H. Nelson

If a piece of iron or steel is placed in a magnetic field it is magnetized by induction. This is true whether the iron or steel is already permanently magnetized or not. Suppose that a permanent magnet is placed in a magnetic field parallel to the direction of the magnet, that is, so that no torque results from the action of the field on the magnet. The strength or magnetic moment of the magnet will be increased (or decreased, if the field of the magnet opposes the applied surrounding field) by induction. The ratio of the change dM, caused by a field of unit-strength, to the original moment M of the magnet is called the induction-coefficient h. The product hM is called the *induction-factor* of the magnet, designated by μ. It will be seen that the induction-coefficient of a magnet changes with a change of moment of the magnet, being inversely proportional to the moment within the range of field-strengths used in this investigation. The induction-factor μ, for all practical purposes in magnetometer-work, may be considered a constant over fairly long periods of time.

This paper deals with a method proposed by the author of determining the induction-coefficient of magnetometer-magnets by using an electrically created magnetic field. If a magnet whose induction-coefficient is to be determined is placed near a suspended magnet (in a magnetometer) in a plane perpendicular to the axis of the suspended magnet, the deflection u of the suspended magnet is a measure of the moment of the deflector. The relation between the moment of the magnet, M, and the angle u is expressed by equation (1)[1].

$$H/M = C \sin u \tag{1}$$

where C is a constant depending on relative positions of the two magnets and on distribution-coefficients. If a magnetic field is now set up around the deflector, parallel to its axis, the moment of the deflector will be increased or decreased by an amount hMX (X being the strength in electromagnetic units of the applied field), and the suspended magnet will be turned through an angle $\triangle u$. If the artificial field is applied in such a way that it has only a vertical component in the region of the suspended magnet, then the angle $\triangle u$ can be attributed solely to a change of moment of the deflector, and equation (2) applies

$$H/M(1-hX) = C \sin(u-\triangle u) \tag{2}$$

Upon reversing the field surrounding the deflector both X and $\triangle u$ take the opposite algebraic sign.

$$H/M(1+hX) = C \sin(u+\triangle u) \tag{3}$$

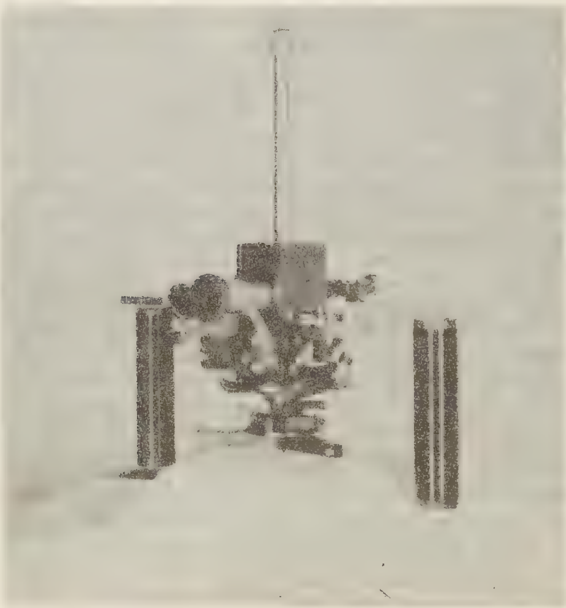
Equations (2) and (3) then yield the following value for h

$$h = (1/X)(\tan \triangle u / \tan u) \tag{4}$$

[1] D. L. Hazard, Directions for magnetic measurements, U. S. Coast Geod. Surv., Ser. No. 166, 3rd Ed. (1930).

This result is derived on the assumption that the moment of the deflector will be changed the same amount for a strengthening field as for a weakening field. As will be shown later this assumption is valid in the present series of tests.

In Figure 1 there is shown a Cooke magnetometer on which are



mounted a special deflection-bar and two solenoids. The solenoids are identical and are placed equidistant from the suspended magnet so that the resultant horizontal component of magnetic field created by them in the region of the suspended magnet is practically zero. Each solenoid consists of 825 turns of No. 30 enameled copper wire wound on an aluminum tube suspended by hooks from the deflection-bar. The diameter of each solenoid is 6.27 cm, and the length is 23.15 cm, both of which dimensions are purely arbitrary except that a greater ratio of length to diameter is more desirable than a smaller one. In practice the two coils are connected in series so that the same current flows in both and so that both fields are directed up (or down) at the same time. Several dry-cells provide the electrical power, and a milliammeter measures the current.

The field inside an infinitely long solenoid is given by

$$X_0 = 0.4\,\pi n I$$

where X_0 is the magnetic field in gauss, n is the number of turns per cm length of the solenoid, and I is the current in amperes.

A coil of finite length, however, produces a weaker field which is given by the equation[2]

$$X_\omega = 0.1(4\pi - \omega_1 - \omega_2)nI$$

where X_ω is the field at any point inside near the middle of the coil, and ω_1 and ω_2 are the solid angles described by drawing elements from the point inside to the last turn of wire at each end of the solenoid.

Figure 2 shows the ratio of (X_ω/X_0) for points along the axis of the solenoids used. An integrated value of X_ω over the length of the magnet

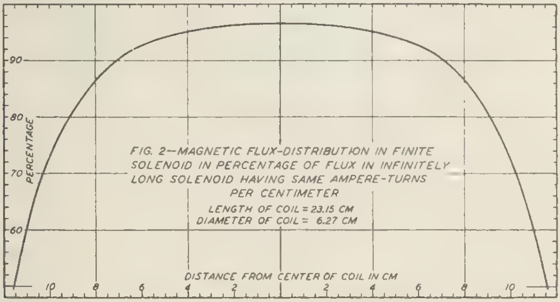


FIG. 2—MAGNETIC FLUX-DISTRIBUTION IN FINITE SOLENOID IN PERCENTAGE OF FLUX IN INFINITELY LONG SOLENOID HAVING SAME AMPERE-TURNS PER CENTIMETER

was used as the magnetizing field acting on any given magnet, and this value is made a maximum by placing the magnet as near the center of the solenoid as possible.

The first tests were made with magnetometer-magnet 37*L* as the deflector. The deflector was placed in four different positions with respect to the suspended magnet, as follows: Deflector east, north end up; deflector east, north end down; deflector west, north end up; deflector west, north end down. In each position readings were made of $\triangle u$ for both upward and downward directions of the applied magnetizing field.

In all tests by this method the initial deflection angle u was read from the horizontal circle of the magnetometer, and the small angle $\triangle u$ was read from the scale in the telescope, thus eliminating the necessity of again reading the circle and of moving the magnetometer, coils, and deflector. Also, deflections of the suspended magnet caused by the electromagnetic field alone (usually of the order of a fraction of a minute of arc) were noted and recorded without the deflector in position so that the angle $\triangle u$ could be corrected for slight unbalance of the solenoids.

Table 1 gives the results of the tests mentioned above. Magnet 37*L* was 9.28 cm long. From the curve, Figure 2, the integrated value over a distance of 9.28 cm near the center of the coil was 95.9 per cent. The current in the coils was 35.0 milliamperes; the effective magnetizing field in the region of the magnet was, therefore, 1.50 electromagnetic units. The magnetic moment, as measured at the Cheltenham Magnetic Observatory, was 874 emu.

A brief study of Table 1 shows that the value of h is very nearly the same for the two directions of the applied field. More extensive

[2]A. W. Smith, Electrical measurements in theory and application, p. 232.

investigation would reveal whether a difference really exists for the comparatively small magnetizing fields encountered in magnetometer-work. These tests with the deflector in various positions relative to the suspended magnet also indicate that, for the accuracy of result desired, nothing is to be gained by using more than one position. The remaining tests herein reported were made using only one relative position of deflector and suspended magnet. Also, the angle $\triangle u$ was taken as half the angle turned through by the suspended magnet upon *complete reversal* of the applied magnetic field. Several reversals were made so that a mean value of the angle $\triangle u$ could be used in the computations.

Table 1—*Induction-coefficient tests on magnet 37L (probably of tungsten steel composition)*

Value	Deflector east				Deflector west			
	North end up		North end down		North end up		North end down	
	X up	X down	X up	X down	X up	X down	X up	X down
u	14°45′23″	14°45′23″	14°57′41″	14°57′41″	14°31′43″	14°31′43″	14°43′35″	14°43′35″
$\triangle u$	12 25	12 40	12 04	12 37	12 25	12 12	12 20	12 08
colog X	9.8239	9.8239	9.8239	9.8239	9.8239	9.8239	9.8239	9.8239
log tan $\triangle u$	7.5577	7.5664	7.5453	7.5647	7.5577	7.5501	7.5548	7.5477
log cot u	0.5794	0.5794	0.5731	0.5731	0.5864	0.5864	0.5803	0.5803
log h	7.9610	7.9697	7.9423	7.9617	7.9680	7.9604	7.9590	7.9519
h	.00914	.00933	.00876	.00916	.00929	.00913	.00910	.00895
h (mean)	.00924		.00896		.00921		.00902	
h (mean)	.00911							
$hM(=\mu)$	7.96							

Table 2 shows the results of a series of tests made on magnet 37*L* several days later to determine whether the strength of the magnetizing field, X, affected the value of the induction-coefficient h.

A new magnet for Cooke Magnetometer 31 (herein designated as magnet 31*LC*) had recently been made of 36 per cent cobalt steel. Since this magnet had not yet been standardized for magnetometer-work an opportunity was afforded to study the induction-coefficient and induction-factor of this steel at various degrees of magnetic saturation. At the

Table 2—*Induction-coefficient, magnet 37L (probably tungsten steel)*

Magnetizing field, X	1.71	1.28	0.86	0.43
u	13°19′51″	13°21′10″	13°20′59″	13°21′06″
$\triangle u$	12′38″	9′29″	6′23″	3′09″
h	00906	00905	.00914	.00902

same time the old magnet for this instrument (herein designated as magnet 31*LT*), probably made of tungsten steel, was treated in a like manner. The magnets were both magnetized to saturation at the National Bureau of Standards, and the induction-coefficients were determined. The magnets were then demagnetized until their moments were about 75 per cent of the saturated value, and again the coefficients were determined. Likewise, tests were run for 50 per cent and 25 per cent of saturation, and for completely demagnetized conditions. For each degree of saturation the approximate moments of the magnets were measured by means of another magnetometer. Table 3 shows the results of the tests on the two magnets.

TABLE 3—*Induction-coefficients of magnets 31LT and 31LC*

Value	Magnet								
	31*LT* (tungsten)					31*LC* (cobalt)			
	Saturation								
	100%	75%	50%	25%	0%	100%	75%	50%	25%
Field X (emu)	1.71	1.71	1.71	1.71	1.71	2.14	2.14	2.14	2.14
u	12°08′23″	8°59′25″	5°58′05″	2°55′06″	0°00′00″	30°23′23″	23°17′01″	15°24′48″	7°30′16″
$\triangle u$	9′36″	9′51″	9′24″	8′57″	9′26″	5′45″	5′13″	5′06″	5′02″
h	.00759	.0106	.0155	.0299	....	.00133	.00165	.00251	.00519
M	1112	827	550	275	0	2660	2078	1381	685
μ	8.47	8.76	8.53	8.23	....	3.54	3.42	3.47	3.56

The induction-coefficient h has no meaning for a demagnetized piece of steel, but the change in moment (from zero-value) was about the same as for the other conditions of saturation.

The final test made by the electromagnetic method of obtaining induction-coefficient was on a round bar of Alnico[3] about 5 cm long and about 6 mm in diameter which had been magnetized to saturation. Because of the low susceptibility of the Alnico to magnetization by induction it was necessary to use a much stronger magnetizing field to get a readable value of $\triangle u$. A current of 200 milliamperes in the solenoid produced an effective field of 8.60 gauss in the neighborhood of the deflector. Two separate determinations yielded the results given in Table 4.

In order to compare the results obtained by this method with those by Lamont's method, four determinations of the induction-coefficient

TABLE 4—*Induction-coefficient of Alnico*

u	13°38′51″	13°39′13″
$\triangle u$	5′59″	5′42″
h	.00083	.00079
M	1240	1240
μ	1.04	0.99

[3]A permanent-magnet alloy of aluminum, nickel, cobalt, and steel.

of magnet $37L$ were made by the latter method using an induction-coefficient apparatus of the Carnegie Institution of Washington recently modified by H. E. McComb and the author to reduce the time required for an observation. These results are given in Table 5.

Several conclusions might be drawn from the results of these tests. In the first place there is provided a check on the results obtained by Lamont's method of determining the induction-factor. Table 5 shows that the new method gave a value approximately 11 per cent higher than the old. A part of this may be attributed to inaccuracies of the constants of the solenoids since they were wound hurriedly with the purpose of testing the possibilities of the method rather than with the idea of making them a permanent piece of standardizing equipment. It is believed, however, that considerably less than half the difference can be accounted for in this way. A study of the apparatus used in Lamont's method might reveal effects on the result caused by lack of horizontality of the axes of rotation of the deflector or effects caused by slight tilting of the entire magnetometer when the deflector is shifted from a position below the suspended magnet to one above it.

Table 5—*Comparison of methods*

Lamont's method		Electromagnetic method (from Table 2)	
h	μ	h	μ
.00808	7.06	.00906	7.92
.00824	7.20	.00905	7.91
.00844	7.38	.00914	7.99
.00798	6.97	.00902	7.89
.00818	7.15	.00907	7.95

The data given in Table 2 answer a question that has probably been asked: Does the induction-factor determined in a larger vertical component of the Earth's field remain constant when the magnet is used parallel to the smaller horizontal component? No systematic difference was noted when the induction-factor was determined at different values of magnetizing intensity.

There has been suggested the possibility of a change in the induction-factor with a change in the moment of the magnet[4]. Table 3 indicates that there is no such change, at least for sudden changes of magnetic moment, in the case of the tungsten and cobalt steels. And it is probably a safe conclusion that this holds equally true for permanent magnets made of other materials.

Two chief advantages of the electromagnetic method may be mentioned. The value of $\triangle u$ is read directly from the scale of the suspended magnet in the magnetometer without the necessity of turning the instrument on its horizontal circle and without disturbing the distance between the deflector and the suspended magnet. This advantage includes the elimination of large changes of the angle u during the period

[4]H. E. McComb, Induction-coefficients for magnetometer-magnets, Terr. Mag., 31, 241-247 (1929).

of observation. The new method, also, is unaffected by slightly disturbed magnetic "weather," for the suspended magnet is turned through the angle $\triangle u$ and individual readings obtained in only a few seconds rather than over a period of 20 to 30 minutes.

Perhaps the greatest advantage of the method is its ability to give accurate values of the induction-coefficient of magnets whose coercive force is very high. The induction-factor of the cobalt steel (Table 3) was only about 40 per cent of that of the tungsten steel, while the induction-factor of the Alnico (Table 4) was only about 12 per cent. If a magnetizing field equal to the vertical component of the Earth's field at the Cheltenham Magnetic Observatory had been used on the Alnico, $\triangle u$ would have been only about 20 seconds of arc, a value which could not be determined accurately by taking differences of circle-readings on the ordinary magnetometer.

The author wishes to acknowledge the cooperation of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington in measuring the magnetic moments of some of the magnets used in this investigation and in permitting the use of its magnetic laboratory for a part of the experimental work.

United States Coast and Geodetic Survey,
Washington, D. C.

NOTES

(See also pages 148, 154, and 191)

24. *Nineteenth annual meeting, American Geophysical Union*—The nineteenth annual meetings of the American Geophysical Union and of its seven sections were held in Washington, D. C., April 27, 28, and 29, 1938. During these meetings over 100 scientific papers dealing with geophysical research were presented. At the General Assembly a symposium on the physics of volcanic processes was held in which five papers of unusual interest were given. There was also a joint meeting of the sections of Meteorology and Oceanography devoted to the presentation of papers dealing with atmospheric and oceanic circulation.

The program of the Section of Terrestrial Magnetism and Electricity included the following contributions: Induction-coefficients of magnetometer-magnets by an electromagnetic method, by J. H. Nelson; Testing the orientation of a declination-variometer by its temperature-coefficient, by H. H. Howe; Alternating-current method of measuring magnetic polarization of rocks, by E. A. Johnson; Density and temperature of the atmosphere to 60 km from twilight-sky brightness measures, by E. O. Hulburt; Correlation of geomagnetic cosmic-ray effects, by T. H. Johnson; Effects of magnetic storms on cosmic-ray intensity, by S. E. Forbush; Latitude-effect in electrical resistance of a column of atmosphere, by O. H. Gish and K. L. Sherman; Ionospheric disturbances coincident with magnetic storms, by L. V. Berkner (presented by H. G. Booker); Asymmetrical characteristics of the Earth's magnetic disturbance-field, by E. H. Vestine; Heights of auroral-zone currents, by A. G. McNish; Recent progress in the study of cosmic correlations with radio reception at Massachusetts Institute of Technology, by H. T. Stetson; The great sunspot of January 1938, by S. B. Nicholson; Preliminary measurements on magnetization of oceanic sediments, by A. G. McNish and E. A. Johnson; Applications of vertical variometer measurements to the study of secular magnetic variations, by Victor Vacquier; Notes on horizontal-pendulum observations in relation to certain phenomena (by title), by F. Napier Denison.

Through the generosity of the American Philosophical Society, a number of copies of the proceedings of the symposium entitled "Geophysical Exploration of the Ocean Bottom," arranged by the American Geophysical Union and held at the American Philosophical Society in Philadelphia, Pennsylvania, November 26, 1937, were distributed to interested members of the Union.

At a smoker held on the evening of April 28, the Chairman and Secretary of the Union set forth in detail the steps being taken in the organization of the meeting of the International Union of Geodesy and Geophysics which is to be held in Washington in September, 1939.

The following resolution submitted by the Planning and Project Committee, the Section of Terrestrial Magnetism and Electricity, and the Section of Oceanography, was duly adopted by the General Assembly of the Union (see page 191 for continuation):

NOTE ON EFFECT OF TORSION IN *QHM* OBSERVATIONS[1]

By H. Herbert Howe

Abstract—Using approximations to the trigonometric functions involved, a simple expression is obtained for the error resulting from imperfect elimination of initial torsion in the fiber.

§ 1. The quartz horizontal-intensity magnetometer, designated *QHM*, consists of a magnet (magnetic moment $=M$) and mirror suspended by a quartz fiber (torsion-constant $=T$), mounted on a theodolite-base. It is adjusted initially so that when the cross-hair in the telescope is coincident with its image reflected from the mirror, the angle (α) between the magnetic axis of the magnet and the magnetic meridian is small. To make an observation, the telescope and torsion-head are turned through an angle $(2\pi+a_1)$ until another coincidence is obtained, a_1 being measured on the graduated circle. The telescope and torsion-head are then turned in the opposite direction through an angle $(4\pi+a_1+a_2)$, to a third coincidence. The changes in the torsion in the fiber are exactly 2π and -4π, respectively.

§ 2. D. la Cour[2] derives the following formulas

$$\tan \alpha=(\sin a_1-\sin a_2)/(2-\cos a_1-\cos a_2) \qquad \text{(IV)}$$

$$H=4\pi T/M\,[\sin (\alpha+a_1)-\sin (\alpha-a_2)] \qquad \text{(V}'\text{)}$$

and states that if the instrument is in good adjustment α is small and, with good approximation

$$H=2\pi T/M \sin [(a_1+a_2)/2] \qquad \text{(VI)}$$

but that if the difference between a_1 and a_2 is rather large it is necessary to use the complete expression involving (IV) and (V′).

§ 3. This note investigates the matter more fully, deriving approximate equations showing how nearly equal a_1 and a_2 must be for (VI) to be valid, and giving the necessary correction if the difference is not negligible but is small enough for the approximations used to be valid. Using the standard formula for the difference of two sines, (V′) becomes

$$H=2\pi T/M \cos [(a_1-a_2+2\alpha)/2] \sin [(a_1+a_2)/2] \qquad (1)$$

Now substitute

$$a_1=\theta+\phi \text{ and } a_2=\phi-\theta \qquad (2)$$

that is

$$\phi=[(a_1+a_2)/2] \text{ and } \theta=[(a_1-a_2)/2] \qquad (3)$$

and we get[3]

$$H=2\pi T/M \sin \phi \cos (\alpha+\theta) \qquad (4)$$

[1]Publication authorized by the Director, United States Coast and Geodetic Survey.

[2]Copenhagen, Met. Inst. Comm. Mag., No. 15, 22 pp. (1936), see p. 5.

[3]Section 4 and the remainder of section 3 are copied with slight changes from an appendix prepared by the author in June 1937 for a translation of la Cour's communication cited above, which was hectographed for the use of the U. S. Coast and Geodetic Survey. The conclusion of section 5 is essentially due to Mr. G. Hartnell.

Therefore, if we let H' be the value given by the approximate equation (VI), the error involved is given by

$$H'/H = \cos(\alpha+\theta) \tag{5}$$

This is an exact expression. When the instrument is in good adjustment, θ and α are small, and we may approximate (IV), expressing angles in radians, by

$$\begin{aligned}\alpha &\doteqdot [\sin(\phi+\theta)-\sin(\phi-\theta)]/(2-2\cos\phi) \doteqdot 2\theta\cos\phi/(2-2\cos\phi)\\ &= \theta\cos\phi/(1-\cos\phi)\end{aligned} \tag{6}$$

Therefore, from (5) and (6)

$$\begin{aligned}H'/H \doteqdot 1-(\alpha+\theta)^2/2 &\doteqdot 1-\theta^2[1+\cos\phi/(1-\cos\phi)]^2/2\\ &= 1-[\theta^2/(1-\cos\phi)^2]/2\end{aligned} \tag{7}$$

$$(H-H') = H\theta^2/2(1-\cos\phi)^2 \tag{8}$$

If θ is expressed in minutes

$$\begin{aligned}(H-H') &= H\theta^2\tan^2 1'/2(1-\cos\phi)^2\\ &= 4.23\times10^{-8}\,H\theta^2/(1-\cos\phi)^2\end{aligned} \tag{9}$$

If an error e is tolerable, we may use (VI) if

$$\begin{aligned}\theta\ (\text{in minutes}) &< \sqrt{e(1-\cos\phi)^2/H\times4.23\times10^{-8}}\\ &= \sqrt{2.36\times10^{7}e/H}\,(1-\cos\phi)\end{aligned} \tag{10}$$

§ 4. *Examples*—At Cheltenham, $H=1.82\times10^4\ \gamma$; suppose $\phi=45°$ then

(*a*) If $\theta=2'$, by (9)
$(H-H')=4.23\times10^{-8}\times1.82\times10^4\times4/0.293^2=0.04\gamma$

(*b*) The error involved in using (VI) is less than 0.5γ if
θ (in minutes) $<\sqrt{2.36\times10^7\times0.5/1.82\times10^4}\,(0.293)=7.5$

§ 5. Dividing (8) by the square of (6)

$$(H-H') = H\alpha^2/2\cos^2\phi \tag{11}$$

Therefore, for a given initial torsion-angle α the error in the result *increases* with increase of mean deflection-angle ϕ, becoming infinite for $\phi=90°$ (that is, the instrument becomes unstable).

UNITED STATES COAST AND GEODETIC SURVEY,
Washington, D. C.

THE IONOSPHERE AT HUANCAYO, PERU, NOVEMBER AND DECEMBER, 1937

By H. W. Wells and H. E. Stanton

On November 17, 1937, at the Huancayo Magnetic Observatory, in Peru, of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, continuous operation of recently-developed ionospheric apparatus[1] was started. (Identical equipment was installed at the Watheroo Magnetic Observatory in Western Australia during April and May 1938.) The new apparatus covers frequencies from 16.0 mc/sec to 0.516 mc/sec every 15 minutes, automatically registering the virtual heights of the ionospheric regions. It is a powerful tool for radio exploration of the Earth's outer atmosphere, and its continuous operation is likely to give an excellent picture of the ionosphere.

From November 17 to December 9 the equipment operated over a limited frequency-range (16.0 to 3.3 mc/sec) pending construction of a long antenna which is required for lower frequencies. Following completion of this antenna, however, the unit has been in practically continuous operation over the full frequency-range of the apparatus. Of the four frequency-sweeps completed between successive hours only the first is normally scaled, while the additional records are examined for unusual effects such as fade-outs or sudden changes indicative of disturbed conditions. Examination shows that normal variations between hourly records are represented sufficiently well by a smooth curve between the hourly values.

Mean hourly values of virtual height and critical frequency for the several ionospheric regions for November and December, 1937, are given in Table 1. The distribution of these data for the recording-period in November and December is shown in Figure 1. The smooth increase during November in E-region ionization to a noon-day maximum followed by a smooth decrease with no appreciable change in height is apparent[2]. The F_1-region follows the same trend as the E-region with less pronounced variation in critical frequencies, while F_1-heights are lowest around noon and higher at other hours when the separation of the F_1- and F_2-regions is less pronounced[3]. Average critical frequencies for the F_2-region reached a minimum at 5^h followed by a rapid rise to a maximum at 9^h. This was followed by the characteristic dip[2,4,5] with subsidiary minimum at 14^h and subsidiary maximum at 18^h, after which night-conditions, characterized by decreasing ionization to 5^h, were prevalent. Heights of the F-region show a minimum at 7^h, just before development of the F_1- and F_2-regions, followed by greater heights for the F_2-region lasting until merging at about 17^h. After sunset a distinct increase in height to values approximately 50 km greater than at midday occurred between 18^h and 20^h and these relatively high heights persisted until 2^h as shown in Figure 1.

[1]L. V. Berkner, H. W. Wells, and S. L. Seaton, Trans. Edinburgh Meeting, September 1936; Internat. Union Geod. Geophys., Ass. Terr. Mag. Electr., Bull. No. 10, 340-357 (1937).

[2]H. W. Wells, Terr. Mag., 39, 209-214 (1934).

[3]L. V. Berkner and H. W. Wells, Terr. Mag., 3 , 215-230 (1934).

[4]L. V. Berkner and H. W. Wells, Proc. Inst. Radio Eng., 22, 1102-1123 (1934).

[5]L. V. Berkner, H. W. Wells, and S. L. Seaton, Terr. Mag., 41, 173-184 (1936).

Table 1—*Mean hourly values of ionospheric data, Huancayo Magnetic Observatory, November and December 1937*

EST	h_E	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$	h_E	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$
	November 17-30, 1937						*December 1-31, 1937*					
h	*km*	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*	*km*	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*
00			336			9.06	98		347	1.14		7.82
01			341			8.74	98		310	1.23		7.64
02			345			8.41	98		293	1.19		6.74
03			291			7.97	97		268	1.07		5.50
04			258			7.20	97		246	.99		5.92
05			254			6.63	96		251	1.01		5.50
06			249			9.29	97		249	2.43		8.30
07			240			11.63	100	216	245	3.02	5.10	10.66
08	102	223	268	3.58	5.30	12.88	100	214	270	3.52	5.28	11.92
09	99	214	281	3.93	5.58	13.40	101	211	286	3.88	5.42	12.37
10	99	209	287	4.14	5.66	13.18	101	207	297	4.17	5.52	12.33
11	98	210	293	4.27	5.70	12.55	100	207	301	4.26	5.52	11.62
12	100	203	292	4.32	5.69	12.00	102	204	313	4.27	5.59	11.46
13	100	202	292	4.27	5.65	11.74	101	201	313	4.20	5.53	11.34
14	102	206	293	4.10	5.55	11.23	99	203	323	4.01	5.60	11.63
15	101	214	298	3.71	5.58	11.63	100	206	310	3.80	5.44	12.09
16	100	227	292	3.38	5.32	11.55	101	218	283	3.45	5.23	12.22
17			275			11.55	100		255	2.81		12.21
18			282			11.98	100		272	1.84		12.11
19			333			11.58	102		316	1.02		11.40
20			346			10.83	101		337	.80		10.40
21			350			10.56	107		360	.89		9.86
22			343			10.07	100		359	1.04		9.37
23			344			9.50	98		348	1.09		8.77

Data for December are presented in the same manner by Figure 1. Extension of the frequency-range gives complete information for the E-region for each hour. The rapid increase in f°_E associated with sunrise began at 5^h, reached its maximum at noon as previously remarked, and smoothly decreased to a minimum at 20^h, after which the trend was generally unchanging until sunrise. The predominant characteristics already discussed for November likewise apply for December. Maximum and minimum average ion-density occurred at the same hours (9^h and 5^h, respectively) as in November. The midday sub-minima for the two months are about equal but the afternoon sub-maximum for December exceeds that for November and closely approaches the maximum value at 9^h.

Evidence of predominance of free electrons over ions at the level where the waves penetrate the E-region is presented by magneto-ionic double refraction. Both doubly-refracted wave-components are recorded in the morning between 5^h and 8^h, and in the evening between 16^h and 20^h. The normal frequency-difference between the two wave-components is approximately 420 kc, which is in close agreement with calculated values[4] based upon the intensity of the Earth's magnetic field and neglecting effects of heavy ions. This indicates that the number of heavy ions does not exceed the number of electrons by more

than 100 times and may be appreciably less during the above-mentioned intervals.

It is proposed to publish ionospheric data in this form each quarter so as to make the material available to interested parties at the earliest possible date. Subsequent reports will include a record of the lowest frequency from which any reflections are received in addition to the above

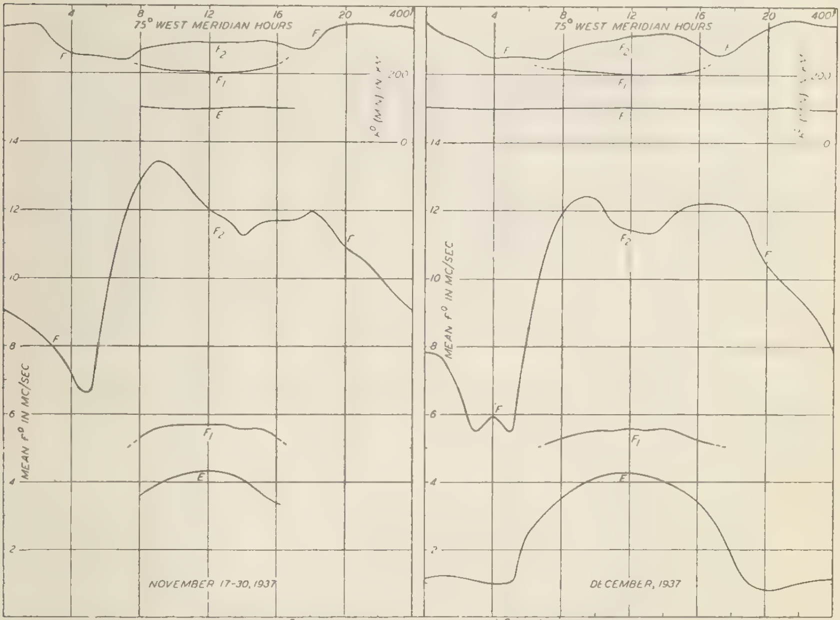


FIG. 1—MEAN CRITICAL FREQUENCY (f^0), MINIMUM VIRTUAL HEIGHT (h^0-MIN), FOR IONOSPHERIC REGIONS, NOVEMBER AND DECEMBER, 1937, HUANCAYO, PERU

results, thereby giving a measure of absorption in the lower regions of the ionosphere.

We express our sincere appreciation to Dr. J. A. Fleming, Director of the Department of Terrestrial Magnetism, whose active interest and support has made possible the instrumental development by L. V. Berkner and the extensive research-program. We are also indebted to Messrs. Tudela and Montero of the Peruvian Government who have favored us with necessary permission and licenses for operation of the ionospheric equipment.

HUANCAYO MAGNETIC OBSERVATORY,
Huancayo, Peru, March 15, 1938

(See also page 199)

PROVISIONAL SUNSPOT-NUMBERS FOR FEBRUARY TO APRIL, 1938

(Dependent alone on observation at Zürich Observatory and its station at Arosa)

Day	February	March	April
1	*M* 62[c]	74	83
2	73[b]	67[d]	81[ad]
3	68[d]	62	80
4	94	45[d]	80
5	*E* 85[ac]	43	93[d]
6	128	*W* 52[c]	97[a]
7	124[d]	78[d]	97[d]
8	110	*E* 71[c]	88[a]
9	101[b]	97[a]	88[d]
10	. . .[b]	*M*106[ac]	106[d]
11	*E*137[cd]	*E*134[c]	110[a]
12	. . .[d]	124[a]	97
13	. . .	161	*M*119[c]
14	*E*200[bc]	149	115[b]
15	171	*M*145[c]	117[d]
16	*E*. . .[ac]	159[d]	133[aad]
17	171[aad]	138[a]	110
18	174[a]	105	112
19	145	80	100
20	98	77[d]	99
21	*M*109[c]	86	89[b]
22	91	64[a]	75[a]
23	*W* 90[ac]	71	*E* 82[cddd]
24	*M* 92[c]	66	95[a]
25	*E* 83[c]	59	*E* 92[c]
26	81[a]	34[b]	92[d]
27	*M*. . .[ac]	. . .[d]	124[dd]
28	85	55	144[ad]
29		*M* 65[c]	144
30		73	105?
31		86[d]	
Means	111.8	87.5	101.6
No. days	23	30	30

Mean for quarter January to March, 1938: 98.1 (71 days)

[a]Passage of an average-sized group through the central meridian.

[b]Passage of a large group or spot through the central meridian.

[c]New formation of a group developing into a middle-sized or large center of activity: E. on the eastern part of the Sun's disc; *W*, on the western part; *M*, in the central-circle zone.

[d]Entrance of a large or average-sized center of activity on the east limb.

Eidgen. Sternwarte,
Zürich, Switzerland

W. Brunner

AVERAGES OF CRITICAL FREQUENCIES AND VIRTUAL HEIGHTS OF THE IONOSPHERE, OBSERVED BY THE NATIONAL BUREAU OF STANDARDS, WASHINGTON, D. C., FEBRUARY TO APRIL, 1938[1]

The following ionosphere data are in continuation of those published for 1934-36 and subsequent issues in this JOURNAL[2]. The symbols used are:

h_E = E-region virtual height, kilometers (lowest measured height)

h_{F_1} = F_1-region virtual height, kilometers (lowest measured height)

h_{F_2} = F_2-region virtual height, kilometers (lowest measured height)

f_E = E-region critical frequency, kilocycles per second, ordinary ray

$f^\circ_{F_1}$ = F_1-region critical frequency, kilocycles per second, ordinary ray

$f^x_{F_2}$ = F_2-region critical frequency, kilocycles per second, extraordinary ray

EST = Eastern standard time (75° west meridian time); add 5 hours for Greenwich time

= Manual measurements

* = Less than ten measurements with automatic recorder

TABLE 1—*Ionosphere data, National Bureau of Standards, Washington, D. C.*

h_E	h_{F_1}	h_{F_2}	f_E	$f^\circ_{F_1}$	$f^x_{F_2}$	h_E	h_{F_1}	h_{F_2}	f_E	$f^\circ_{F_1}$**	$f^x_{F_2}$
		*February, 1938**						*March, 1938*			
		295			6330			288			7205
		302			6175			292			6980
		309			5985			297			6697
		305			5820			299			6410
		295			5610			294			6073
		294			5300	...		297	800#		5713
...		294	1100#		5085	...		278	1500#		5927
..		253	1750#		6700	...		244	2250#		8032
...		233	2480		9450	122	242*	235	2820		9640#
121		232	2980		11412#	121	232	288	3251	4750#	10720#
118	229	245	3290		12525#	120	226	304	3480	4950#	11440#
118	228	248	3455		13200#	118	224	324	3632	4950#	11600#
118	227	245	3568		13625#	120	224	331	3682	5000#	11760#
119	230	255	3565		13500#	119	229	334	3696	5000#	11800#
119	231	252	3453		13487#	120	232	328	3600	4800#	11760#
120	233	252	3240		13275#	121	235	316	3402	4750#	11720#
122		237	2840		13125#	125	236	296	3057	4500#	11560#
...		235	2294		12600#	...		256	2593		11500#
		228	1470#		11550#	...		242	2000#		11290#
		235			10300#			244			10350#
		238			9000			253			9242
		249			8000			261			8510
		264			7310			279			7992
		275			6815			282			7672

*F_1-layer critical frequencies not well enough defined to measure.
**For ionosphere storm day of March 23 only. $f^\circ_{F_1}$ not well enough defined to measure on ionospherically quiet days

[1]Communicated by the director of the National Bureau of Standards of the United States Department of Commerce.

[2]T. R. Gilliland, S. S. Kirby, N. Smith, and S. E. Reymer, Terr. Mag., **41**, 379-388 (1936).

TABLE 1—*Ionosphere data, National Bureau of Standards, Washington, D. C.*—*Continued*

EST	h_E	h_{F_1}	h_{F_2}	f_E	$f^o_{F_1}$	$f^o_{F_2}$
h			*April, 1938*			
00			309			7583
01			310			7325
02			317			6983
03			300			6546
04	...		309	800♯		6042
05	120♯		309	1050♯		5811
06	120♯		268	2180♯		5536
07	120♯	247	283♯	2696	3860	7778
08	119	238	305♯	3136	4300*	8602
09	117	231	302♯	3487	4925♯	9260♯
10	118	224	318♯	3680	5100♯	9790♯
11	118	225	341♯	3779	5250♯	10500♯
12	119	226	336♯	3839	5265♯	10860♯
13	116	230	327♯	3812	5215♯	11110♯
14	119	235	326♯	3700	5125♯	10960♯
15	118	237	317♯	3569	5130♯	10600♯
16	121	239	304♯	3287	4600*	10450♯
17	121	246	288♯	2848	3794	10380♯
18	120♯		264	2412♯		10120♯
19	...		255	1282♯		9543
20			260			9080
21			275			8559
22			293			8111
23			303			7807

NATIONAL BUREAU OF STANDARDS,
UNITED STATES DEPARTMENT OF COMMERCE,
Washington, D. C.

AMERICAN *URSI* BROADCASTS OF COSMIC DATA[1], JANUARY TO MARCH, 1938, WITH AMERICAN MAGNETIC CHARACTER-FIGURE C_A, FEBRUARY TO APRIL, 1938

The data for terrestrial magnetism, sunspots, and solar constant are the same as given in previous tables.

The first three columns of the Table give (1) the magnetic character according to the scale 0-2 of the International Commission of Terrestrial Magnetism and Atmospheric Electricity, (2) the type featuring the day other than normal by the letters *b*, *p*, *o*, and *i* for days marked by bay, rapid pulsations, long-period oscillations, and irregular oscillations, respectively, and (3) the hour and minute of Greenwich mean time marking the beginning of a storm, the end of the storm being indicated in the foot-note to the Table. The next two columns give the data relating to sunspots: (1) the number of groups of spots and (2) the total number of spots. It is to be noted that sunspot-numbers such as those from Zürich can be obtained from the number of groups and spots given in the Table by the formula $N=k\ (10g+s)$, where the mean value of k for Mount Wilson was 0.53 during 1936; during 1937 this value varied from 0.47 to 0.66 with an average value of 0.53.

[1]For previous announcements see Terr. Mag., **35**, 184-185 and 252-253 (1930); **36**, 54, 141, 258-259, and 358-360 (1931); **37**, 85-89, 189-192, 408-411, and 484-487 (1932); **38**, 60-63, 148-151, 262-265, 335-339 (1933); **39**, 73-77, 159-163, 244-247, 353-356 (1934); **40**, 111-115, 220-222, 334-336, 449-452 (1935); **41**, 85-87, 207-209, 315-317, 407-409 (1936); **42**, 89-91, 207-209, 316-319, and 411-415 (1937); **43**, 83-87 (1938).

Summary American URSI daily broadcasts of cosmic data, January to March, 1938

Greenwich date	January						February						March					
	Magnetism				Sunspot		Magnetism				Sunspot		Magnetism				Sunspot	
	Character	Type	GMT beginning disturbance		Groups	Number	Character	Type	GMT beginning disturbance		Groups	Number	Character	Type	GMT beginning disturbance		Groups	Number
			h	*m*					*h*	*m*					*h*	*m*		
1	0	...	..	..	8	115	0	...	..	..	...	...	1	*i*	..	..	7*	70
2	0	...	..	..	...	...	0	...	..	..	...	...	1	*i*				
3	0	*b*	00	00	7	85	0	...	..	..	...	...	0	...				
4	1	*i*	02	40	8	45	0	...	..	..	...	...	0	...				
5	1	*i*	..	..	8	65	0	...	..	..	10	95	1	*p*				
6	0	...	..	.	7	55	1	*i*	02	30	8	100	0					
7	0	...	..	..	...	...	1	*i*	..	..	10	135	0					
8	1	...	..	..	8	55	1	*i*	10	40	...	...	0					
9	1	...	..	..	6	45	1	*i*	..	..	...	...	0	...	..	..	...	.
10	0	...	..	..	6	60	1	*i*	14	00	...	...	0	...	..	..	9	145
11	0	...	..	..	7	50	1	*i*	00	00	...	...	0	...	..	..	...	.
12	1	*i*	17	00	7	55	0	...	..	..	...	...	0	...	..	..	...	..
13	1	*i*	..	..	9	120	1	*i*	20	35	17	300	0	...	..	..	...	...
14	0	...	..	..	...	...	1	*i*	..	..	...	...	0	...	..	..	11	125
15	0	...	..	..	...	...	0	...	..	..	...	...	0	...	..	..	13	90
16	2	*i*	22	40	9	90	0	...	..	..	13	200	0					
17	2	*i*	..	..	...	...	0	...	..	..	13	180	0	...	..	..	12	80
18	1	*i*	14	20	7	80	0	...	..	..	...	...	0	...	..	..	11	65
19	1	*i*	..	..	8	195	0	...	..	..	9	100	0	...	..	..	9	50
20	1	*i*	5	00	9	70	0	...	..	..	6	35	0	...	..	..	8	55
21	1	*i*	..	..	11	80	0	*b*	9	12	10	105	1	*i*	22	00	6	25
22	2	*i*	5	28	13	100	0	...	..	..	11	50	1	*i*	..	..	5	35
23	0	...	..	..	15	100	0	...	..	..	8	50	2	*i*	17	00	6*	35*
24	0	...	..	..	11	75	0	...	..	..	8	65	2	*i*	..	..	6	35
25	2	*i*	11	51	10	65	0	...	..	..	7	55	1	*i*	23	30	3	30
26	2	*i*	..	..	11	65	0	...	..	..	7	45	1	*i*	..	..	3	20
27	0	...	..	..	12	70	0	...	..	..	...	...	0	...	..	..	3	15
28	0	...	..	..	9	50	1	*i*	12	12	...	...	0	...	..	..	3	25
29	0	...	..	..	...	...							0	...	..	..	...	...
30	0	...	..	..	8	85							0	...	..	..	4	30
31	1	*i*	19	25	...	...							0	...	..	..	7	40
Mean	0.7	...	....		...	...	0.3	...	....		...	...	0.4	...	....			

*Revision of value originally broadcast.

Greenwich mean time for ending of storms: 11^h, January 5; 11^h, January 13; 24^h, January 17; 20^h, January 19; 19^h, January 22; 6^h, January 26; 24^h, January 31; 3^h, February 7; 11^h, February 11; 24^h, February 14; $10^h\ 12^m$, February 21; 2^h, March 2; 11^h, March 23; 11^h, March 24; 3^h, March 26.

Mount Wilson Observatory is now supplying corrections and additions to the sunspot-data which are broadcast in the *URSI*gram. So far as possible, these additional and corrected values will be used in this tabular summary and will be designated as such in foot-notes to the Table.

Beginning January 1, 1934, the magnetic information of the *URSI*-

Kennelly-Heaviside Layer heights, Washington, D. C., January to March, 1938
(Nearest hour, Greenwich mean time, of all observations is 17)

Date	Freq.	Ht.	Date	Freq.	Ht.	Date	Freq.	Ht.	Date	Freq.	Ht.
1938	*kc/sec*	*km*	*1938*	*kc/sec*	*km*	*1938*	*kc/sec*	*km*	*1938*	*kc/sec*	*km*
Jan. 5	2,500	110	Jan. 26	12,200	490	Feb. 23	2,500	120	Mar. 9	13,000	*
" "	3,180	140	" "	12,600	380	" "	3,400	160	" 16	2,500	120
" "	3,200	270	" "	13,000	480	" "	3,500	330	" "	3,700	160
" "	3,350	230	" "	13,200	*	" "	3,800	220	" "	3,780	280
" "	4,400	240	Feb. 2	4,600	250	" "	4,400	240	" "	4,000	220
" "	6,200	250	" "	7,000	280	" "	5,400	250	" "	4,400	230
" "	9,400	280	" "	9,400	300	" "	7,000	270	" "	5,400	270
" "	9,400	320	" "	10,200	310	" "	9,400	320	" "	7,800	300
" "	11,000	320	" "	12,000	330	" "	11,000	340	" "	10,200	330
" "	11,000	370	" "	12,000	380	" "	11,000	370	" "	11,000	340
" "	11,200	330	" "	12,600	330	" "	12,000	380	" "	11,000	360
" "	11,200	410	" "	12,600	420	" "	12,000	460	" "	11,800	370
" "	11,800	360	" "	12,800	340	" "	12,400	410	" "	11,800	420
" "	12,000	430	" "	12,800	470	" "	12,400	600	" "	12,000	380
" "	12,400	*	" "	13,200	380	" "	12,800	470	" "	12,000	440
" 12	2,500	120	" "	13,600	520	" "	13,200	570	" "	12,400	400
" "	3,430	130	" "	13,800	*	" "	13,400	*	" "	12,400	530
" "	3,450	270	" 9	2,500	120	May 2	2,500	120	" "	12,800	450
" "	3,700	220	" "	3,500	170	" "	3,000	120	" "	13,200	540
" "	4,400	240	" "	3,580	260	" "	3,500	160	" "	13,400	*
" "	5,400	250	" "	3,850	220	" "	3,600	310	" 23	2,500	120
" "	7,000	250	" "	4,400	240	" "	3,900	230	" "	3,600	140
" "	9,400	310	" "	5,400	270	" "	4,400	240	" "	3,650	300
" "	9,400	350	" "	7,000	280	" "	5,400	260	" "	3,800	240
" "	10,200	340	" "	9,400	290	" "	7,000	280	" "	4,400	330
" "	10,200	430	" "	11,000	310	" "	9,400	310	" "	4,800	390
" "	10,600	370	" "	12,000	310	" "	11,000	330	" "	4,900	770
" "	10,600	690	" "	12,000	340	" "	11,000	350	" "	5,000	640
" "	11,000	460	" "	13,000	330	" "	12,000	350	" "	5,300	520
" "	11,200	560	" "	13,000	350	" "	12,000	400	" "	5,600	570
" "	11,400	*	" "	13,600	340	" "	12,600	370	" "	6,000	610
" 19	4,600	270	" "	13,600	440	" "	12,600	530	" "	6,100	600
" "	7,000	260	" "	14,000	370	" "	13,000	410	" "	6,400	570
" "	9,400	280	" "	14,400	490	" "	13,400	530	" "	6,700	680
" "	10,200	300	" "	14,600	*	" "	13,600	*	" "	6,800	*
" "	11,800	320	" 16	2,500	120	" 9	2,500	120	" 30	2,500	120
" "	11,800	350	" "	3,500	200	" "	3,300	120	" "	3,700	150
" "	12,600	340	" "	3,550	310	" "	3,500	160	" "	3,700	310
" "	12,600	530	" "	3,900	230	" "	3,630	250	" "	4,000	220
" "	13,000	380	" "	4,400	230	" "	3,700	180	" "	4,400	230
" "	13,400	530	" "	5,400	240	" "	3,740	270	" "	4,600	250
" "	13,600	*	" "	7,000	280	" "	3,900	220	" "	5,400	270
" 26	2,500	120	" "	8,600	310	" "	4,400	240	" "	6,200	290
" "	3,100	130	" "	10,200	340	" "	5,400	260	" "	8,600	300
" "	3,300	*	" "	11,000	340	" "	7,000	290	" "	11,000	340
" "	3,370	260	" "	12,000	340	" "	9,400	310	" "	11,000	390
" "	3,500	230	" "	12,000	360	" "	11,000	340	" "	11,400	360
" "	4,400	240	" "	12,400	340	" "	11,000	380	" "	11,400	420
" "	6,200	260	" "	12,400	400	" "	11,600	360	" "	11,800	370
" "	8,600	270	" "	12,800	370	" "	11,600	420	" "	11,800	550
" "	10,200	300	" "	12,800	600	" "	12,000	380	" "	12,200	410
" "	11,400	310	" "	13,000	390	" "	12,000	530	" "	12,600	550
" "	11,400	350	" "	13,400	500	" "	12,400	410	" "	12,800	*
" "	12,200	340	" "	13,600	*	" "	12,800	470			

*No value obtained.

American magnetic character-figure C_A for Greenwich half-days based on reports from Cheltenham, Honolulu, Huancayo, San Juan, Sitka, Tucson, and Watheroo for February to April, 1938

Day	February		March		April	
	0^h-12^h	12^h-24^h	0^h-12^h	12^h-24^h	0^h-12^h	12^h-24^h
1	0.5	0.6	0.9	0.8	0.0	0.3
2	0.5	0.4	0.3	0.1	0.1	0.2
3	0.6	0.6	0.0	0.0	0.1	0.4
4	0.2	0.6	0.0	0.3	0.4	0.4
5	0.3	0.1	0.8	1.1	0.0	0.0
6	1.1	1.1	0.6	0.5	0.9	0.8
7	0.7	1.0	0.1	0.2	0.7	0.6
8	0.5	1.4	0.0	0.0	0.4	0.2
9	0.9	0.9	0.0	0.0	0.2	0.5
10	1.2	0.4	0.0	0.0	0.2	0.4
11	0.9	0.2	0.0	0.1	0.3	0.6
12	0.3	0.3	0.9	0.6	0.4	0.7
13	0.4	0.7	0.1	0.2	0.6	1.3
14	1.0	0.9	0.4	0.4	1.6	1.1
15	0.1	0.1	0.4	0.2	0.6	0.5
16	0.1	0.0	0.0	0.0	2.0	1.7
17	0.1	0.1	0.0	0.1	0.7	0.9
18	0.1	0.1	0.0	0.0	0.9	0.6
19	0.0	0.0	0.0	0.0	0.5	0.4
20	0.0	0.1	0.0	0.0	0.1	0.1
21	0.1	0.0	0.0	0.6	0.1	0.1
22	0.0	0.1	1.4	0.9	0.4	0.8
23	0.6	0.7	1.0	0.9	0.8	1.0
24	0.3	0.2	1.4	0.2	0.6	0.4
25	0.2	0.6	0.4	0.4	0.6	0.6
26	0.1	0.5	0.9	0.4	0.1	0.3
27	0.1*	0.6*	0.1	0.0	0.4	0.2
28	0.7	0.8	0.0	0.0	0.0	0.0
29			0.1	0.6	0.1	0.0
30			0.0	0.0	0.0	0.0
31			0.0	0.0		
Means	0.4	0.5	0.3	0.3	0.5	0.5
	0.4		0.3		0.5	

*Sitka not reporting.

gram is for Cheltenham, Maryland, instead of Tucson, Arizona. In addition to this change in observatory, beginning November 1, 1937, the data cover the 24 hours of the Greenwich day ending at 19^h, 75° west meridian mean time instead of the 24 hours ending at 8^h, 75° west meridian mean time.

In accordance with information received from Dr. C. G. Abbot, Secretary of the Smithsonian Institution, on March 6, 1937, solar-constant values were discontinued owing to important change in methods.

The data for the table of Kennelly-Heaviside Layer heights which is self-explanatory are supplied by the National Bureau of Standards.

As set forth in this JOURNAL for June, 1937, "The Department of Terrestrial Magnetism and United States Coast and Geodetic Survey with the cooperation of the United States Army and United States Navy communication-services and several amateur radio stations have undertaken to supply an American character-figure based upon the reports

of the seven American-operated observatories—those of the Department of Terrestrial Magnetism at Huancayo in Peru and at Watheroo in Western Australia, and those of the United States Coast and Geodetic Survey at Cheltenham (Maryland), Honolulu (Hawaii), San Juan (Puerto Rico), Sitka (Alaska), and Tucson (Arizona)." This character-figure is being designated C_A, and the values for February to April, 1938, are given in the accompanying Table.

H. F. Johnston

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

INTERFERENCE WITH TELEGRAPH SERVICE DURING LATTER PART OF JANUARY, 1938, CAUSED BY MAGNETIC STORM

The following report from the Traffic Department of the Western Union Telegraph Company gives information on the severity and extent of interference with service during the latter part of January caused by the magnetic storm associated with Aurora Borealis:

"While there was some interference noted on the circuits up and down the Pacific Coast, the maximum interference occurred elsewhere throughout the country, the transcontinental circuits being most seriously affected. The disturbance started on January 22, at which time the interference was comparatively slight, and gradually increased in intensity until the afternoon of the 25th, when maximum readings in excess of 400 volts were recorded in many parts of the country.

"During the periods when these foreign potentials exceeded the potentials regularly used on our circuits, it was necessary to suspend operation on some types of circuits and wait until the surges had subsided. The length of these surges was about the same as previously recorded in such cases (seldom exceeding ten minutes), but the frequency with which they occurred and the rate at which the potentials increased from zero to maximum were much greater than ever before experienced. Notwithstanding the severity of the 'storm,' Western Union circuits were less affected than during previous disturbances of this nature due to the use of recently developed methods for combatting such interference.

"After the point of maximum interference was reached on January 25 conditions cleared rapidly, and by the afternoon of the 26th all circuits were back to normal.

"Similar effects were recorded on our oceanic cable-circuits, and we have the following interesting comment from our cable superintendent at Heart's Content, Newfoundland:

" 'The recent severe magnetic disturbance commonly called Aurora was the most spectacular within our memory. The sky at night assumed a bright reddish color comparable with a beautiful sunset. Aurora is usually confined to the sky in the north but in this instance it was visible in the sky to the south. The brilliancy practically turned night into day.' "

J. C. Willever

The Western Union Telegraph Company,
60 Hudson Street, New York, N. Y.,
February 16, 1938

DISCUSSION OF S. CHAPMAN'S NOTE ON RADIO FADE-OUTS AND THE ASSOCIATED MAGNETIC VARIATIONS

In response to Dr. Fleming's suggestion I am glad to comment on Dr. Chapman's Note above mentioned. Dr. Chapman showed that Dr. Birkeland had listed as a separate type of magnetic perturbation an occurrence in 1902 which is now seen to be one of the type associated with sudden disturbances of the ionosphere caused by solar eruptions. Dr. Birkeland's discernment is an interesting instance of partial recognition of this cosmic phenomenon as revealed by various early records and publications. Other instances, to which I have previously called attention, are the observation by T. L. Eckersley of a separate type of radio transmission interruption in 1928, and the simultaneous occurrences of magnetic perturbations and solar eruptions in 1859, 1872, etc.

The outlines of the entire phenomenon emerged in 1935 and early 1936, when it was discovered that radio, magnetic, earth-current, and solar effects occur simultaneously, that the three terrestrial effects have characteristics differentiating them from other vagaries (for example, magnetic storms), that are manifestations of a disturbance in the ionosphere, that this disturbance is a sudden increase in ionization below the *E*-layer caused by ultra-violet radiation from a solar eruption, and that the effects vary from a maximum in those latitudes and longitudes where the Sun's rays are vertical to zero in the night hemisphere.

Dr. Chapman raised the question of terminology of the magnetic aspect of this cosmic phenomenon. He proposed the term "S_q-augmentation" for this type of magnetic perturbation. A. G. McNish proposed the term "solar-flare disturbance" for it. The writer is not qualified to weigh the merits of these proposals, and would simply suggest that a term not be standardized until we are more certain that the characteristic mentioned in the name associated with this type of magnetic disturbance is both unique and necessary.

J. H. Dellinger

National Bureau of Standards,
Washington, D. C., May 11, 1938

AURORA OF JANUARY 22, 1938, AT BISMARCK, NORTH DAKOTA

An unusually extensive and brilliant auroral display was observed at Bismarck, North Dakota, on the morning of January 22, 1938. When first noticed by the writer at $3^h\ 20^m$, it was mostly white (some red showing low in the north). It consisted of long narrow streamers reaching from close to the horizon to the zenith with rapid and steady pulsations which seemed to travel in waves from the horizon to the zenith. The aurora predominated in the northeast where the streamers were so close together as almost to form a sheet, although shorter streamers were visible in all directions, a number of which were broken into small segments.

At $4^h\ 20^m$ the aurora was not so bright and consisted chiefly of an arc in the south about 7° wide and 120° long composed of vertical streamers. The ends of the lower edge of this arc were about 4° above the horizon, the central position of the lower edge arching to 12° above the horizon in the south.

About 20 minutes later a bright sheet was visible low in the west, its lower northern edge coming within 2° of the horizon. This joined

the southern arch at $4^h\ 20^m$ which extended further eastward, the whole covering over 180° of arc. The southwest portion was over 30° wide, the lower half of this portion being white and the upper half, except for a white upper edge, being red. The eastern end, although not so bright nor lasting so long, also showed a red hue and looked something like a low cloud of uniform texture.

At $5^h\ 15^m$, the whole sky, except for the low portions below the northeast and southwest arches was more or less covered with vertical streamers broken into a number of segments. Most of these were white, but large patches of red were observed at different times which were usually located about 30° to 50° above the horizon.

The phenomenon died out gradually after $5^h\ 20^m$ but was again prominent at $6^h\ 00^m$ when the streamers were again pulsating rapidly, extending in all directions from about 30° above the horizon to a point of convergence near the zenith, the sky for about 10° all around the zenith being at times almost completely covered. The streamers were mostly white although a broad red streamer appeared in the southeast.

At $7^h\ 00^m$ the display consisted mainly of a broad red or rose-colored streamer extending from about 30° above a point slightly north of the western horizon across the converging point to about 60° above the eastern horizon from which point it changed to white and extended to within about 40° of the horizon. Other segments and isolated patches of vertical streamers in white were also observed at this time.

After $7^h\ 15^m$ the aurora faded quite rapidly into the light of dawn although a few streamers and patches were faintly visible as late as $7^h\ 30^m$.

In general, the aurora was most extensive in the northeast, west, and southwest. All streamers converged, or, if extended, would have converged at a point approximately 73° above the south-southwest horizon (azimuth 194° from north around by east). The sky was cloudless until almost noon on this day and, during all observations described above, the moon was shining brightly in its third quarter.

The phemenonon was also observed by many people during the evening of January 21, although it is believed to have reached the point of greatest brilliancy and intensity at about $5^h\ 15^m$ on January 22.

Warren O. Langer

Bismarck, North Dakota

PROVISIONAL SOLAR AND MAGNETIC CHARACTER-FIGURES, MOUNT WILSON OBSERVATORY, JANUARY, FEBRUARY, AND MARCH, 1938

Greenwich civil time						Range Hor. int.
Beginning			Ending			
1938	*h*	*m*	*d*	*h*	*m*	γ
Jan. 16	22	38	18	5	..	300
22	1	..	22	21	..	450
25	11	51*	26	6	..	440
Feb. 6	3	09	6	21	..	170
8	11	..	10	14	..	140
Mar. 21	22	..	22	17	..	180

January 1938

Day	K_2 A	K_2 B	$H\alpha B$ A	$H\alpha B$ B	$H\alpha D$ A	$H\alpha D$ B	No. groups	Mag'c char.
1	2	2	2^c	2	2	0	8	0
2	...	...	...	...	...	...	...	0
3	2	0	2	0	2	2	7	0
4	2	1	2	1	3	4	8	1
5	2	2	2	2	3	3	8	0
6	2	3	2	3	3	3	7	0.5
7	...	...	...	...	...	...	7^h	0.5
8	3	2	3	2	2	0	8	0.5
9	3	2	3	2	3	1	6	0
10	3	3	3^c	3^d	2	1	6	0
11	3	4	3	4^d	2	2	7^i	0
12	3	3	...	...	...	...	7	0.5
13	3	1	3	1	2	1	9	1
14	...	...	...	...	...	...	...	0
15	...	...	...	...	...	...	...	0
16	3	2	3	2^d	2	1	9	0.5
17			...	...			...	2
18			...	...	...	...	7^k	1
19				...	...	...	8^a	0.5
20	4	4	3?	$3?^d$	3?	2?	9	1
21	4	4	4	3^d	3	1	11	1
22	4	4	4	3	3	2	13	2
23	4	4	4	4	4	4	15	0.5
24	4	4	4	4	4	3	11	0.5
25	4	4	4	4	4	4	10	2
26	4	4	3	3	3	1	11	1
27	3	4	3	3	3	1	12^b	0.5
28	3	3	3	3	3	1	9	0
29	...	...	...	...	...	...	...	0
30	3	1	3?	1?	3?	4?	8	0
31	...	...	...	...	...	...	...	1
Mean	3.1	2.8	3.0	2.5	2.8	2.0	8.8	0.6

February 1938

Day	K_2 A	K_2 B	$H\alpha B$ A	$H\alpha B$ B	$H\alpha D$ A	$H\alpha D$ B	No. groups	Mag'c char.
1	...	...	...	...	...	...	...	0
2	...	...	...	...	...	...	...	0
3	...	...	...	...	...	...	...	0.5
4	...	...	...	...	...	...	...	0.5
5	4	3	3	2	3	3	10^e	0
6	4	3	3	3	3	3	8	1.5
7	4	4	4	3	3	1	10	1
8	...	...	...	...	...	...	8	1
9	...	...	...	...	...	...	...	1
10	...	...	...	...	...	...	$..^h$	1
11	...	...	...	...	...	...	...	0.5
12	...	...	...	...	...	...	10	0
13	4	4	4	3	3	2	17^b	0.5
14	...	...	...	...	...	...	$..^i$	1
15	...	...	...	...	...	...	...	...
16	5	5	...	...	...	...	13	0
17	5	5	5	5	3	2	$13^{e, g}$	0
18	...	...	...	...	...	...	$..^f$	0
19	4	4	4?	4?	2?	1?	9	0
20	4	3	4	3^d	2	1	6	0
21	3	3	3	3	2	2	10^a	0
22	4	4	...	...	...	...	11	0
23	3	3	4	4	2	1	8	0.5
24	3	2	3	2	2	2	8^g	0
25	3	3	3	3	2	0	7	0.5
26	...	...	...	...	...	...	7	0
27	...	...	...	...	...	...	...	0
28	...	...	...	...	...	...	...	0.5
Mean	3.8	3.5	3.6	3.2	2.5	1.6	9.7	0.4

March 1938

Day	K_2 A	K_2 B	$H\alpha B$ A	$H\alpha B$ B	$H\alpha D$ A	$H\alpha D$ B	No. groups	Mag'c char.
1	...	...	...	...	...	...	7	0.5
2	...	...	...	...	...	...	...	0
3	...	...	...	...	...	...	...	0
4	...	...	...	...	...	...	4	0
5	...	...	...	...	...	...	5	1
6	...	...	...	...	...	...	...	0.5
7	...	...	...	...	...	...	...	0
8	...	...	...	...	...	...	...	...
9	...	...	...	...	...	...	...	0
10	...	...	...	...	...	...	9^j	0
11	...	...	...	...	...	...	...	0
12	...	...	...	...	...	...	$..^e$	0.5
13	...	...	...	...	...	...	...	0
14	...	...	...	...	...	...	11	0.5
15	4	4	4	3	3	2	13	0
16	4	4	...	...	...	...	11	0
17	4	4	4	3	4	4	12	0
18	4	3	4	3	4	4	11	0
19	4	3	3	3^d	4	2	9	0
20	3	4	3	3	3	2	8	0
21	...	...	...	...	...	...	6	0.5
22	3	4	...	...	...	...	5	1
23	...	...	...	...	...	...	6	1
24	3	3	3	3^d	3	2	6	1
25	3	3	3	3	2	2	3	0.5
26	3	3	3	3	2	1	3^f	0
27	3	3	3	3	2	1	3	0
28	...	...	...	...	...	...	3	0
29	...	...	...	...	...	...	...	0.5
30	...	...	...	...	...	...	4	0
31	3	3	3	2?	2	2	7	0
Mean	3.4	3.4	3.3	2.9	2.9	2.2	7.0	0.2

NOTE—For an explanation of these tables see this JOURNAL, **35**, 47-49 (1930).

?Indicates an uncertain value which should be given low weight.

The character-figures of solar phenomena are estimated from the spectroheliograms which are made with a 2-inch solar image, usually in the early morning. The very bright chromospheric eruptions are reported in these notes if observed at any time during the day.

a, b Formation of a new group which later developed to average size or larger; (a) less than 30° from the center of the disk, (b) more than 30° from the center of the disk.

c, d Very bright chromospheric eruptions; (c) less than 30° from the center of the disk, (d) more than 30° from the center of the disk.

e, f, g, h, i, j, k, l Passage of a large or active group across the central meridian within 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40° of the center of the disk, respectively

A very large group crossed the Sun's disk between January 12 and 24 in latitude 17° north. It was comparable in size with the two largest groups of 1937, which crossed the central meridian on July 28 and October 4, respectively. A very bright chromospheric eruption occurred in this group on January 20 between 18^h and 21^h, GMT. Large prominences of the fountain-like spot-type were observed over the spot at the west limb on January 24.

Three very great magnetic storms occurred between January 12 and 26. The first, January 16-18, began when the center of the group was 21° east of the central meridian. The second, January 22, began 29 hours after the bright eruption of January 20 when the group was 47° west of the central meridian. An exceptionally bright aurora was seen at Mount Wilson in the early morning hours of January 22 while this storm was in progress. The third, January 25-26, occurred one day after the group had passed around the west limb of the Sun. These three magnetic storms were the largest that have been recorded here for several years and each caused widespread interference with telephone and telegraph communications.

The most active group on the Sun during the magnetic storms of February 6 and 8 crossed the central meridian in latitude 24° south on February 10.2.

A large group which crossed the central meridian on March 26.9 in latitude 15° south was 66° east of the central meridian when the magnetic storm of March 21 began. A much smaller group was, however, almost exactly central on the solar disk at March 22.3.

Carnegie Institution of Washington,
Mount Wilson Observatory,
Pasadena, California

Seth B. Nicholson
Elizabeth Sternberg Mulders

PRINCIPAL MAGNETIC STORMS

Sitka Magnetic Observatory

January to March, 1938[1]

(Latitude 57° 03'.0 N., longitude 135° 20'.1 or 9^h 01^m.3 W. of Gr.)

January 4—A small disturbance began gradually at about 10^h GMT and gradually increased in intensity to a maximum at 13^h 30^m. Thereafter the disturbance subsided; the trace had gradually returned to about normal values at 24^h January 24. Ranges: *D*, 74'; *H*, 799 gammas; *Z*, 608 gammas.

January 12-13—A magnetic disturbance began slowly with a pronounced bay at about 7^h GMT, January 12. The elements remained quiet until 17^h when the activity began to increase gradually. An abrupt decrease of about 65' in *D* at around 4^h January 13, and another of about 30' at 8^h 45^m were the periods of maximum activity. Thereafter the storm decreased to normal values at 12^h January 13. Ranges: *D*, 90'; *H*, 833 gammas; *Z*, 613 gammas.

January 16-17—After several hours of increasing activity, a major magnetic storm began with an abrupt commencement at 21^h 36^m GMT. The declination and horizontal intensity started so abruptly and of such large amplitudes that it was impossible to distinguish the exact amount of movement. The initial motion is estimated at 166' in *D*, and about 500 gammas in *H*. Thereafter the storm increased in intensity with short-period pulsations superimposed on long bays. The maximum intensity was reached at 11^h 45^m, January 17. Until 17^h the elements moved with such rapid motion that it was impossible to follow the movement accurately. Between 21^h 19^m and 22^h 09^m, January 17, there was a short period of increased activity. By 24^h, January 17, the trace was nearly normal, though moderately disturbed. This general storminess continued until the next storm on January 21. Estimated ranges: *D*, 253'; *H*, 2008 gammas; *Z*, 2383 gammas.

January 21-22—After four days of moderately disturbed magnetic conditions a second major storm began gradually at about 8^h GMT, January 21, and with increasing activity reached a maximum at 8^h 17^m, January 22. Thereafter the elements were badly disturbed until 18^h, January 22. During this interval the elements could be identified occasionally. However at times the motion was so violent that it was impossible to distinguish the various traces. By 20^h, January 22, the elements were nearly normal. Estimated ranges: *D*, 247'; *H*, 1996 gammas; *Z*, 1397 gammas.

January 25-26—A magnetic storm began at 11^h 52^m GMT, January 25, with a sudden increase of 105 gammas in *H*, and corresponding changes in the other elements. The activity of the elements gradually increased to a maximum at 17^h 45^m and remained disturbed until about 20^h. During the next four hours the motion gradually decreased. The trace remained disturbed until 20^h, January 26. The storm was marked by a steady decrease of horizontal intensity of approximately 1000

[1]Communicated by the Director, United States Coast and Geodetic Survey.

gammas below normal values. Ranges: *D*, 151′; *H*, 1465 gammas; *Z*, 1225 gammas.

February 5-7—A period of magnetic disturbance began gradually at $02^h\ 35^m$ GMT, February 6, and continued disturbed until 24^h, February 7.

February 8-11—A continued period of minor magnetic disturbance started gradually at 10^h GMT, February 8, and continued with short intervals of increased activity throughout several days. The disturbance ceased about 12^h February 11. Ranges: *D*, 92′; *H*, 1008 gammas; *Z*, 640 gammas.

February 13-14—A small magnetic storm began abruptly at $20^h\ 35^m$ GMT, February 13. The elements remained quiet until $08^h\ 25^m$, February 14, and then began to increase gradually in intensity to maximum values at 12^h. After 17^h they began a gradual return to normal, and were calm by 22^h, February 14. Ranges: *D*, 136′; *H*, 734 gammas; *Z*, 504 gammas.

March 5-6—A minor magnetic disturbance began gradually at 13^h GMT, March 5, and after four hours of moderate activity returned slowly to normal. The trace remained moderately disturbed until 10^h, March 6.

March 22-24.—After three hours of increasing magnetic activity a sudden commencement at $08^h\ 35^m$ GMT, March 22, marked the beginning of a small magnetic storm. The elements remained disturbed for several days with large bays and several short intervals of increased activity. Each outburst was of gradually increasing intensity. A maximum was reached at 03^h, March 24. The storm continued until 11^h, March 24, at which time it ceased suddenly. Ranges: *D*, 143′; *H*, 1215 gammas; *Z*, 578 gammas.

Robert E. Gebhardt, *Observer-in-Charge*

Cheltenham Magnetic Observatory

January to March, 1938[1]

(Latitude 38° 44′.0 N., longitude 76° 50′.5 or $5^h\ 07^m.4$ W. of Gr.)

January 12-13—A mild disturbance began about 22^h GMT, January 12, and lasted until 16^h, January 13. The oscillations were irregular with no outstanding features.

January 16-18—A severe storm began at $22^h\ 36^m$ GMT, January 16, when *D* decreased 48′ in west declination in 32 minutes and *H* increased 136 gammas in 50 minutes. *D* returned to normal values 50 minutes after its minimum but continued to be disturbed. *H* fell gradually to below normal values. The first three hours of the storm were characterized by short-period oscillations in all three elements, the short-period oscillations of *D* and *H* being superimposed on the movements described above. There were irregular oscillations until $11^h\ 35^m$, January 17, when all the elements became very active for six hours. During these hours *D* increased in west declination about 1° in 50 minutes, *H* decreased 260 gammas in three hours, and *Z* reached its maximum value. Again much short-period activity was superimposed on the

[1]Communicated by the Director, United States Coast and Geodetic Survey.

larger movements. Another interval of great activity lasted from $21^h\ 20^m$ to $23^h\ 30^m$, January 17, but this time the larger movements were of much less amplitude. After midnight of January 17 the storm gradually died down with the usual low mean values of H. The ranges during the entire storm were: D, 113′; H, 48 gammas; Z, 233 gammas. The storm ended at midnight January 18.

January 22—After more than a day of moderate disturbance a severe storm began at $05^h\ 28^m$ GMT, January 22. The storm began with an increase of H of 37 gammas in about two minutes. The changes in D and Z were more gradual. Between $06^h\ 15^m$ and $07^h\ 10^m$ Z decreased 235 gammas, it then increased 207 gammas in the next 50 minutes. At $08^h\ 15^m$ Z again decreased rapidly to the minimum value of the storm. H and D were severely disturbed from the beginning of the storm until $08^h\ 15^m$ when the disturbance changed abruptly to a violent phase and all three elements were greatly agitated until 15^h. From 15^h until 19^h the elements were severely disturbed with short-period oscillations. The storm ended at midnight January 22. The ranges were: D, 123′; H, 588 gammas; Z, 750 gammas.

January 25-26—A magnetic storm of great severity began abruptly at $11^h\ 51^m$ GMT, January 25, with sudden changes of small amplitude in the three elements. All through the storm short-period oscillations were imposed on the irregular longer period perturbations. At $15^h\ 45^m$ the storm became severe and between 18^h, January 25, and 01^h, January 26 it was quite violent. It then subsided and ended at 05^h, January 26. The ranges were: D, 135′; Z, 799 gammas; H, more than 875 gammas. The maximum of H was lost beyond the edges of the magnetograms from two magnetographs. The rapidity of the changes may be judged from the fact that the minimum value of D occurred 45 minutes after its maximum and the extreme values of H occurred within an hour of each other. During the violent part of the storm the mean values of H and Z were greater than normal values.

January 31—A disturbance of short duration began abruptly at $19^h\ 23^m$ GMT, January 31. It ended at 24^h of the same day. The ranges were: D, 14′; H, 124 gammas; Z, 139 gammas.

February 6-11—A moderate disturbance began distinctly but not abruptly at $02^h\ 30^m$ GMT, February 6. However, a sudden change in all elements took place at $03^h\ 09^m$. Comparatively large ranges occurred in all the elements between 05^h and 07^h, February 6. The field continued moderately disturbed until about noon February 11, with greater activity during the night than during daylight.

February 13-14—A mild disturbance began abruptly at $20^h\ 38^m$ GMT, February 13. The abrupt increase in H was 30 gammas but the increases in D and Z were small. The disturbance was characterized by short-period oscillations and it ended at 24^h, February 14.

March 21-24—A disturbed period began March 21 at 22^h and continued through several days. Until 17^h, March 23, the perturbations were of moderate intensity, but at that time the disturbance assumed storm-proportions. The storm continued until 11^h, March 24. During this portion D and Z were more disturbed than H. The ranges were: D, 43′; H, 245 gammas; Z, 224 gammas.

Albert K. Ludy, *Observer-in-Charge*

Apia Observatory

January to March, 1938

(Latitude 13° 48′.4 S., longitude 171° 46′.5 or 11^h 27^m.1 W. of Gr.)

January 16-18—A sudden commencement occurred at 00^h 44^m GMT, January 16, when *H* increased 56 gammas. After this the traces were only slightly disturbed until 22^h 37^m when rapid oscillations in *H* and *Z* were recorded. *H* fell gradually through a range of 281 gammas until 18^h 52^m, January 17, when it returned to normal values though it continued to show slight disturbances. Ranges: *Z*, 32 gammas; *D*, 9′.

January 22-23—After small disturbances there was a sudden drop in *H* of 130 gammas at 06^h 40^m GMT, January 22, and a further very rapid drop from 09^h 35^m through a range of 319 gammas until 10^h 52^m. *H* remained in this region until 12^h 55^m after which conditions rapidly returned to normal. Ranges: *D*, 10′; *H*, 434 gammas; *Z*, 63 gammas.

January 25-26—A sudden commencement occurred at 11^h 51^m GMT, January 25, with a sharp increase of 44 gammas in *H* which was followed by a gradual decrease until 23^h 17^m when conditions returned to normal. The oscillations in *H* and *Z* were rapid. Ranges: *D*, 8′; *H*, 340 gammas; *Z*, 48 gammas.

February 6-11—The elements were slightly disturbed after an increase in *H* of 7 gammas at 02^h 30^m GMT, February 6, which was followed by a further sharp increase of 24 gammas at 03^h 9^m. *D* and *Z* were similarly changed by small amounts. The disturbance had ended by February 11.

J. Wadsworth, *Director*

Huancayo Magnetic Observatory

January to March, 1938

(Latitude 12° 02′.7 S., longitude 75° 20′.4 or 5^h 01^m.4 W. of Gr.)

January 16-17—A marked sudden commencement occurred at 22^h 37^m GMT, January 16. In one minute, *H* increased 250 gammas, *Z* increased 24 gammas and then decreased 13 gammas, and *D* moved 2′.3 west and then 4′.4 east. Rapid oscillatory motions of the *H*-spot continued until about 02^h, January 17. Milder activity prevailed until 12^h when severe and rapid changes began in horizontal intensity lasting until 18^h. Between 14^h and 15^h there was a 355-gamma bay in *H*. The minimal value in *H* was 29320 gammas at 16^h 25^m. There was another period from 21^h 20^m to 24^h during which *H* was quite disturbed. The storm ended about 24^h, January 17. Ranges: *D*, 12′.8; *H*, 505 gammas; *Z*, 62 gammas.

January 22—A fairly intense magnetic storm began at 02^h GMT, January 22, and ended at 23^h, January 22. Throughout this period there were rapid fluctuations of large magnitude in horizontal intensity. *H* changed 420 gammas, *D* 18′, and *Z* 42 gammas in the hour from 9 to 10. Ranges: *D*, 31′; *H*, 540 gammas; *Z*, 74 gammas.

January 25-26—A sudden commencement occurred at 11^h 53^m GMT, January 25. In an interval of one minute *H* increased 53 gammas and *Z* 6 gammas, while *D* moved slightly easterly. A severe magnetic storm followed characterized by large fluctuations in all elements until 22^h, January 25. An abnormally deep bay in *H* occurred between 20^h,

January 25, and 14^h, January 26. The traces were moderately disturbed from 14^h to 20^h, January 26. Ranges: D, 22′; H, 1125 gammas; Z, 146 gammas.

January 31—A strong magnetic storm began at 10^h 30^m GMT, January 31, and ended at 24^h. Very large fluctuations in H were recorded. There was a deep bay in H from 16^h 50^m to 19^h 24^m during which period the daily maximum normally occurs. The mean value of H over this period was approximately 200 gammas below normal. From 16^h 50^m to 20^h 30^m, Z values were about 35 gammas above normal. Ranges: D, 9′; H, 307 gammas; Z, 60 gammas.

February 6-8—A sudden commencement occurred at 03^h 10^m GMT, February 6. In three minutes, D moved slightly easterly, H increased 46 gammas, and Z increased 7 gammas. A moderate magnetic storm followed lasting until 22^h, February 8, the daylight hours during this period being very disturbed. Ranges: D, 13′; H, 434 gammas; Z, 100 gammas.

February 13-14—A sudden commencement occurred at 20^h 37^m GMT, February 13. In a period of three minutes D moved slightly westerly, H increased 51 gammas, and Z increased 4 gammas. The hours following were only slightly disturbed. The traces became moderately disturbed at 12^h, February 14, remaining so until 20^h, February 14. Ranges: D, 9′; H, 171 gammas; Z, 36 gammas.

March 5—The period 15^h to 20^h GMT, March 5, was very disturbed with a number of large fluctuations in H.

March 12—A moderate disturbance lasted from 14^h to 16^h GMT, March 12.

March 21-24—A magnetic storm of moderate intensity commenced at 20^h, 43^m GMT, March 21 and continued until about 5^h 30^m, March 24. Ranges: D, 11; H, 360 gammas; Z, 57 gammas.

Frank T. Davies, *Observer-in-Charge*

Watheroo Magnetic Observatory

January to March, 1938

(Latitude 30° 19′.1 S., longitude 115° 52′.6 or 7^h 43^m.5 E. of Gr.)

January 16-17—This storm, beginning at 22^h 30^m GMT, January 16, reached its greatest intensity on January 17. Ranges: D, 38′; H, 246 gammas; Z, 254 gammas.

January 22—This severe storm, beginning at 02^h 40^m GMT, January 22, was very active in all elements from 05^h 20^m to 12^h 00^m. The maximum value in H occurred at 06^h 26^m and the minimum at 11^h 35^m. An aurora was visible from 13^h 00^m to 13^h 30^m which is unusual at this low latitude. The storm ended at 22^h, January 22, though H and Z at this time were somewhat low and high respectively. Ranges: D, 42′; H, 496 gammas; Z, 473 gammas (estimated).

January 25-26—This severe storm began with a sudden commencement at 11^h 51^m GMT, January 25. D moved westerly 7′ in three minutes of time and then easterly 4′ in four minutes. H increased 69 gammas in two minutes followed by a decrease of 34 gammas in four minutes. The numerical value of Z decreased 4 gammas abruptly, then increased 27 gammas in three minutes and decreased 27 gammas in

three minutes. The storm ended about 18^h, January 26. Ranges: D, 39′; H, 358 gammas; Z, 245 gammas.

January 31 There was a sudden commencement at $19^h\ 22^m$ GMT, January 31. D moved westerly 1′ abruptly, then 5′ easterly in three minutes. H increased 46 gammas in three minutes and the numerical value of Z increased 6 gammas abruptly followed by a decrease of 29 gammas during the next three minutes. Ranges during the following four hours: D, 10′; H, 77 gammas; Z, 68 gammas.

J. W. GREEN, *Observer-in-Charge*

MAGNETIC OBSERVATORY, CAPETOWN

OCTOBER, 1937, TO MARCH, 1938

(*Latitude 33° 57′ S., longitude 18° 28′ or $1^h\ 13^m.9$ E. of Gr.*)

Note: The absolute values of D and Z are negative and that of H is positive; the changes indicated by sign are in the algebraic sense.

October 3-4—A sudden commencement was recorded at $11^h\ 05^m$ GMT, October 3, which lasted for 35 hours. The sudden changes were +4′ in five minutes in D, +28 gammas in five minutes in H, and +30 gammas in ten minutes in Z. The ranges were: D, 25′; H, 149 gammas; Z, 101 gammas.

October 7-13—A sudden commencement was recorded at $05^h\ 20^m$ GMT, October 7, with an increase of 20 gammas in five minutes in H. The disturbances on October 7 and 8 were small. There were strong outbursts on October 9 and 11. The storm continued until 00^h, October 13. The ranges were: D, 31′; H, 150 gammas; Z, 154 gammas.

October 15—Sharp bays extending over a period of about 50 minutes developed with peaks about $19^h\ 45^m$ GMT, October 15. The changes were −9′ in 20 minutes and +10′ in 20 minutes in D, +50 gammas in 22 minutes and −32 gammas in 35 minutes in H, and +52 gammas in 30 minutes and −32 gammas in 25 minutes in Z.

November 7-8—A small sudden commencement started at $17^h\ 00^m$ GMT, November 7, with an increase of 15 gammas in seven minutes in H. The disturbances, which were small, continued for about 30 hours. The ranges were: D, 22′; H, 50 gammas; Z, 80 gammas.

November 29—A sudden commencement began at $11^h\ 05^m$ GMT, November 29, with an increase of 32 gammas in six minutes in H. The disturbances continued for about 11 hours. The ranges were: D, 14′; H, 100 gammas; Z, 90 gammas.

November 30 A bay developed about 21^h GMT, November 30, with the following changes: D, −6′ in 70 minutes and +7′ in 35 minutes; H, +80 gammas in 70 minutes and −45 gammas in 35 minutes; Z, +50 gammas in 70 minutes and −32 gammas in 30 minutes.

December 18-19—Gradual-commencement disturbances, which continued for about 35 hours, gave ranges of 22′ in D, 132 gammas in H, and 139 gammas in Z.

December 23—A sudden commencement was recorded at $10^h\ 47^m$ GMT, December 23, which lasted about nine hours. There was a sudden increase of 20 gammas in five minutes in H. The ranges were: D, 26′; H, 153 gammas; Z, 164 gammas. A bay developed on December 23 at about $18^h\ 30^m$.

January 2-13—Small disturbances started at 08^h GMT, January 2, and continued until 01^h, January 3 On January 4 a small sudden commencement started at $02^h\ 45^m$ with changes of $+2'$ in six minutes in D, $+8$ gammas in six minutes in H, and continued until 10^h, January 5. On January 6 bays extending over a period of about one hour, with peaks at about $17^h\ 40^m$, developed on all elements with ranges of $-3'$ and $+5'$ in D, -35 gammas and $+35$ gammas in H, and -44 gammas and $+56$ gammas in Z. There were gradual-commencement disturbances from 09^h, January 7, to 06^h, January 8. On January 12 a gradual-commencement storm started about 16^h and continued for about 14 hours. At about 22^h, D decreased $9'$ in one-half hour and then increased $14'$ in one-half hour. H increased 40 gammas in one hour and decreased about 45 gammas in the next hour, while at the same time Z increased about 95 gammas and then decreased 60 gammas.

January 16—On January 16 at 22^h GMT there were three complete oscillations of small amplitude in D, H, and Z in a period of about 27 minutes and then a sudden increase of $10'$ in 15 minutes in D and an oscillatory decrease of $10'$ in 30 minutes, while H increased 85 gammas in five minutes with a further oscillatory increase of 35 gammas in 25 minutes and then decreased 180 gammas in two hours. Z increased 88 gammas in 33 minutes and then decreased 160 gammas in two hours.

January 17-21—On January 17 at about $11^h\ 30^m$ GMT there was another outburst with changes in 30 minutes as great as $20'$ in D, 60 gammas in H, and 65 gammas in Z. There was a further outburst at $21^h\ 05^m$ with an increase of $13'$ in 10 minutes in D, 60 gammas in H, and 88 gammas in Z in 30 minutes. The ranges on January 17 were: D, $41'$; H, 150 gammas; Z, 260 gammas. On January 18 the storm continued but was of small intensity. The intensity increased somewhat from 17^h to 22^h. The disturbances on January 19 and 20 were much smaller, but on January 21 at about $22^h\ 30^m$ there was a fresh outbreak with variations such as $18'$ in four minutes in D and 90 gammas in seven minutes in H. From 9^h to 11^h, January 22, there were ranges of $42'$ in D, 300 gammas in H, and 160 gammas in Z. The ranges of the storm on January 21 to 22 were about $47'$ in D, 375 gammas in H, and 200 gammas in Z.

January 25-29—On January 25 there was a large sudden commencement at $11^h\ 52^m$ GMT, which lasted about 15 hours. There were variations of the nature of $36'$ in 25 minutes in D, 115 gammas in 15 minutes in H, and 200 gammas in 20 minutes in Z. The ranges were about $49'$ in D, 350 gammas in H, and 265 gammas in Z. On January 29 bays developed over a period of about an hour with peaks at about $22^h\ 30^m$, with ranges of $6'$ in D, 30 gammas in H, and 50 gammas in Z.

January 31—On January 31 a sudden commencement started at $19^h\ 22^m\ 46^s$ GMT, with an increase of 30 gammas in five minutes in H. The storm lasted for about two and one-half hours. The ranges were: D, $13'$; H, 75 gammas; Z, 80 gammas.

February 2-4—Small bays developed on the magnetograms of each element with the centers of the bays at about 00^h, $16^h\ 30^m$, and $15^h\ 00^m$ GMT, February 2, 3, and 4, respectively.

February 6-11—A storm began at $02^h\ 30^m$ GMT, February 6, with an increase of $1'$ in three minutes in D, 10 gammas in five minutes in H, and 6 gammas in five minutes in Z. Small oscillations followed until $03^h\ 09^m$, when there was a sudden increase of $6'$ in D, 11 gammas in H,

and 16 gammas in *Z*, each in four minutes. The storm continued until 18^h, February 7, with ranges of 17′ in *D*, 155 gammas in *H*, and 100 gammas in *Z*. There was a fresh outbreak at $10^h\ 30^m$, February 8, with ranges of 20′ in *D*, 165 gammas in *H*, and 144 gammas in *Z*. From $15^h\ 40^m$, February 8, *H* decreased 150 gammas in three hours, then increased 125 gammas in two and one-half hours, and again decreased 55 gammas in one hour. From the same time *Z* decreased 120 gammas in two hours, and then increased 65 gammas in two hours with a slight increase during the next hour, a further increase of 60 gammas, and then a decrease of 60 gammas, each in one hour. The changes in *D* were of the order of 10′ in one hour. The disturbances from 00^h, February 9, were small, with an increase of intensity from 10^h, February 10, for four hours. There was a recurrence of small disturbances from 23^h, February 10, to 10^h, February 11.

February 13-14—Small disturbances started at 08^h GMT, February 13, with an increased intensity from $20^h\ 35^m$, February 13, to 18^h, February 14.

February 25—Small disturbances began at 10^h GMT, February 25, and continued until 20^h with the formation of small bays on each element at $17^h\ 30^m$.

February 28-March 1—Disturbances started at $19^h\ 45^m$ GMT, February 28, and continued until 21^h, March 1, with bays starting at about $19^h\ 10^m$. *D* decreased 5′ in 27 minutes and then increased 7′ in 43 minutes. *H* increased 45 gammas in 40 minutes and then decreased 23 gammas in one hour, while *Z* decreased 24 gammas in 20 minutes, increased 56 gammas in 45 minutes, and decreased 36 gammas in one hour.

March 6-7—At $01^h\ 50^m$ GMT, March 6, *D* increased 19′ in 30 minutes and then decreased 7′ in 40 minutes. *H* increased 19 gammas in 20 minutes and then decreased 20 gammas in one hour, while *Z* increased 30 gammas in 30 minutes and then decreased 36 gammas in 45 minutes. From $12^h\ 50^m$, March 6, to $02^h\ 15^m$, March 7, the changes were −25′ and +21′ in *D*, −117 gammas and +200 gammas in *H*, and −145 gammas and +140 gammas in *Z*.

March 12—On March 12 at 00^h GMT oscillatory disturbances started and continued for 16 hours.

March 21-23—At $22^h\ 37^m$ GMT, March 21, *D* increased 3′ in four minutes and then decreased 2′ in six minutes, while *H* increased 40 gammas in six minutes and decreased 20 gammas in six minutes and *Z* increased 30 gammas in eight minutes and decreased 20 gammas in 25 minutes. The storm continued until about 10^h, March 23, but broke out again at 18^h, March 23, with the development of large bays of the order of ±13′ in *D*, ±50 gammas in *H*, and ±60 gammas in *Z*. The ranges were about 140 gammas in *H* and 100 gammas in *Z*.

March 25-27—At $23^h\ 24^m$ GMT, March 25, a sudden-commencement storm started with +1′ in *D*, +20 gammas in *H*, and +12 gammas in *Z*, each in four minutes. The storm lasted for four hours with the development of bays starting at $01^h\ 10^m$, March 26, with ±10′ in *D*, ±15 gammas in *H*, and +32 gammas and −50 gammas in *Z*. Small bays developed on the magnetograms of each element at 01^h, March 27.

A. Ogg, *Magnetic-Survey Adviser*

Trigonometrical Survey Office,
Capetown

NOTES

(See also pages 148, 154, and 166)

"WHEREAS, the need for more complete and more accurate magnetic data is constantly increasing by reason of the extension of navigation by air and by sea and of scientific and commercial exploration by geophysics, and WHEREAS, many of the present stations on land, including repeat-stations, are no longer suitable for magnetic observations owing to local disturbance occasioned by the growth of cities and towns, and WHEREAS, no adequate observations have been obtained in waters adjacent to the United States and its territories and possessions since the destruction of the *Carnegie* in 1929, and WHEREAS, this lack of observations at sea and on land is a serious handicap to the construction of accurate magnetic charts over land and sea, therefore be it RESOLVED, that the American Geophysical Union strongly urge that a complete resurvey be made of the continental United States and its possessions and territories, this survey to include the establishment of additional stations where needed and a series of basic repeat-stations in places not likely to be subject to local disturbance in the future, and be it further RESOLVED, that every effort be exerted by the United States Government to procure, through one of its agencies, a non-magnetic vessel capable of continuing the work of the *Carnegie*, and be it further RESOLVED, that copies of this resolution be sent to the President of the United States, the Secretary of the Navy, the Secretary of Commerce, and the Director of the Coast and Geodetic Survey."

25. *Personalia*—Dr. *E. van Everdingen*, director in chief of the Royal Meteorogical Institute of the Netherlands, was retired on March 1, 1938, at the age of 65 years, and by royal decree of February 16, 1938, Dr. *H. G. Cannegieter*, was appointed as his successor, effective from July 1, 1938. During the interval, March 1 to June 30, 1938, Dr. van Everdingen will continue to discharge the duties of director in chief.

Professor *B. F. J. Schonland*, Director of the Bernard Price Institute of Geophysics, University of the Witwatersrand, Johannesburg, has been elected a Fellow of the Royal Society of London.

Dr. *Rudolph Geiger* has been appointed Professor of Physics and Meteorology at the Forstliche Hochschule, Eberswalde, Germany.

Leo Otis Colbert has been appointed Director of the United States Coast and Geodetic Survey in succession to Rear-Admiral *R. S. Patton*, who died November 25, 1937. Rear-Admiral Colbert, before his appointment to the directorship, was Chief of the Division of Charts of the Survey.

Prof. *William Lawrence Bragg*, Director of the National Physical Laboratory, has been appointed Cavendish Professor of Experimental Physics in the University of Cambridge in succession to the late Lord Rutherford.

Dr. *J. A. Fleming*, Director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, was elected a member of the National Academy of Sciences, April 27, 1938.

Dr. *Julius Maurer*, formerly Director of the Eidgenössische Meteorologische Zentralanstalt of Switzerland, died on January 21, 1938, aged 79 years.

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By H. D. Harradon

A—Terrestrial and Cosmical Magnetism

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Clay, J.; and E. M. Bruins. Magnetic storm and variation of cosmic rays. Physica, The Hague, v. 5, No. 2, 1938 (111-114). [The magnetic storm between April 24 and May 6, 1937, was accompanied by a decrease of cosmic-ray intensity at Amsterdam of maximum 5 per cent. At $\lambda=54°$ only corpuscles of an energy lower than 8×10^9 eV were influenced. In some cases, but not in all, a parallelism occurs between the variation of intensity and the variation of H. The decrease of the cosmic-ray intensity can be explained by a decrease of the normal intensity of the circular currents around the Earth.]

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Observações meteorológicas, magnéticas e sismológicas feitas no Instituto Geofísico nos anos de 1934 a 1936. 2a. Parte—Magnetismo terrestre. Volumes LXXIII a LXXV. Coimbra, Tip. da Gráfica de Coimbra, 1937 (iv+6+6+5). 30 cm.

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Caractère magnétique de chaque jour des mois juillet-septembre 1937. De Bilt, 1938, 4 pp. 32 cm. [Published under the auspices of the Association of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics.]

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LETTERS TO EDITOR

REQUEST FOR INFORMATION ABOUT THE GIANT PULSATION ON APRIL 22, 1938

During the Polar Year Dr. Thorkelsson, head of the Meteorological Service of Iceland, arranged for registrations, using a quick-run magnetograph placed at his disposal by the International Commission for the Polar Year 1932-1933. As generally known, the records obtained from Iceland were remarkably interesting because they showed a greater frequency of giant pulsations than ever reported from other regions of the world. In view of this fact it was proposed by Professor S. Chapman and the writer at the Edinburgh Assembly of the International Association of Terrestrial Magnetism and Electricity that a thorough investigation of the giant pulsations should be carried out through international collaboration under the auspices of the Association. A committee on the subject was set up and the Association budgeted for £400 for those researches.

The proposal submitted to the Association aimed at a temporary establishment in Iceland of four quick-run magnetographs to determine the height above the Earth of the current-system in question. However, although the registerings of giant pulsations made by the relatively numerous quick-run recorders established in Northern Scandinavia during the Polar Year have shown that the giant-pulsation phenomenon is of a rather local character, it was not clear beforehand what would be the most convenient distance between the contemplated stations in Iceland. For the purpose of investigating this question and also for learning whether the giant pulsations were still frequent in Iceland the Danish Meteorological Institute, in collaboration with the Danish Postmaster-General and Dr. Thorkelsson, established two transportable stations near Reykjavik, each provided with a sensitive quick-run magnetograph. These stations began work early in August 1937 and continued until the middle of December last, when the registrations were interrupted because not a single giant pulsation had occurred. In Northern Scandinavia a giant pulsation was registered on September 13, 1937, but since then no other giant pulsation has been reported from there.

While the giant pulsations have thus vanished from the regions where formerly they were frequent, a giant pulsation with the characteristic oscillation of about 100 seconds was registered on April 22, 1938, so far to the south as at the Magnetic Observatory of Copenhagen. Figure 1-A shows how the records look for the slow-speed magnetograph and Figure 1-B shows the quick-speed magnetogram for the day in question. As far as I know a similar giant pulsation has never been registered before at the Copenhagen Observatory.

The purpose of this note is to request observatories to examine their magnetic and earth-current registerings for April 22, 1938, and, in case a giant pulsation has occurred, to provide the Committee on Giant Pulsations with copies of the records and with the data necessary for

Scales for slow-speed record should read 100, 200, and 200 gammas instead of 50, 100, and 100 gammas.

the interpretation of those registerings. Copies both of quick-run records and of those made at slow speed would be valuable. Observatories are requested not to hesitate to ask the Bureau of the Committee to make copies of their registerings by forwarding their originals to the bureau in Copenhagen (Toldbodvej 15) which will return them after a few days.

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Terrestrial Magnetism
and
Atmospheric Electricity

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ON COSMIC-RAY EFFECTS ASSOCIATED WITH MAGNETIC STORMS

S. E. FORBUSH

Abstract—Evidence indicates that the storm-time field of some magnetic storms causes world-wide changes of several per cent in cosmic-ray intensity. That other magnetic storms of equal intensity at the Earth's surface occur with no appreciable cosmic-ray effects definitely indicates that the entire current-system for the storm-time field of both types of storms can not be located at the same distance above the Earth. In particular, the possibility that the current-systems responsible for the two types of storms both lie within the Earth's atmosphere appears remote. Assuming the current-system for the storm-time field of both types of storms to consist of a ring concentric with the Earth in the geomagnetic equatorial plane, magnetic data are analyzed to determine whether the radius of the assumed ring is, as would be expected, greater for magnetic storms which affect cosmic-ray intensity. Although the analysis is not conclusive on this point, the results satisfy a necessary condition for the existence of such a ring-current. The occurrence of aurora in temperate latitudes during most of the magnetic storms which affected cosmic-ray intensity is interpreted, after Störmer, to indicate the existence of such ring-currents. The percentage-changes in cosmic-ray intensity during magnetic storms is within the observational uncertainty the same at geomagnetic latitudes 50°.1 north and 0°.6 south. The significant correlation between changes in daily means of cosmic-ray intensity, for two stations separated 50° in latitude, probably results from the same mechanism responsible for the magnetic-storm effect.

Introduction

The world-wide decrease in cosmic-ray intensity which occurred during the magnetic storm commencing April 24, 1937, we ascribed [see reference 1 at end of paper] directly to the magnetic field of the storm. We assumed after S. Chapman [2] that the axially symmetric part of the field of the magnetic storm was due to a system of westward electric currents in the upper atmosphere. In the region outside such a current-system its magnetic field is approximately equivalent to that which would result from an increase in the Earth's dipole-moment. Provided the effect on cosmic rays of the field inside such a current-system is negligible, its effect on cosmic-ray intensity we concluded [1] would be similar to that resulting from an increase in the Earth's moment, namely, a decrease, according to the well-known theories of Störmer and of Lemaître and Vallarta.

S. Chapman [3] pointed out that the magnetic-storm effect on cosmic-ray intensity should provide determination of the height above the Earth at which flow the electric currents responsible for magnetic storms. He suggested, as a convenient model, a current-system, in the form of a spherical sheet concentric with the Earth, having an external field for

which the existing theory of orbits of cosmic-ray particles would apply, but indicated that in the region inside this current-system the existing theory of orbits was not applicable. On the basis of the decrease in cosmic-ray intensity and in horizontal magnetic intensity which occurred during the magnetic storms near the end of April 1937, J. Clay and E. M. Bruins [4], neglecting the effects of the internal field of the current-system suggested by S. Chapman, estimated the radius of the assumed spherical sheet to be about three times that of the Earth. They concluded, however, that the field of the magnetic storm could not be due to the setting up of such a current-system since this should cause "an increase of cosmic-ray intensity in the same way as was found by Störmer [5] for the aurorae." To escape this difficulty Clay and Bruins assumed that the magnetic storm and the effect on cosmic-ray intensity could only be explained by a decrease of current-intensity in a normally existing current-system.

That aurora may appear in temperate latitudes coincident with definite decreases in cosmic-ray intensity is indicated by reports [6] of aurora in New England on April 25 and 26, 1937, during which period a significant world-wide decrease in cosmic-ray intensity was observed (see Fig. 5). V. F. Hess, R. Steinmaurer, and A. Demmelmair [7] noted a considerable decrease in cosmic-ray intensity, strikingly similar to that in our Figure 2, during the appearance, over most of Europe, of aurora or January 25, 1938.

An aurora was also seen on the evening of January 22, 1938, at the Watheroo Magnetic Observatory (latitude 30° south, longitude 116° east) of the Department of Terrestrial Magnetism. This corresponds to about 8^h, 75° west meridian mean time, January 22, for which Figure 2 indicates a considerable decrease in cosmic-ray intensity.

Thus a current-ring of several earth-radii, concentric with the Earth and in the geomagnetic equatorial plane of the type which Störmer [8] required to explain the incidence of aurorae farther southward during magnetic storms, may also explain the observed decrease in cosmic-ray intensity. Chapman [2, 3] in indicating objections to a ring of such large radius as was assigned by Störmer pointed out that such a ring would likely alter considerably the normal paths of cosmic-ray particles. He concluded [2] that if such a type of ring exists its radius is probably not more that a few times that of the Earth.

The cathode-ray experiments of Brüche [9] and of Birkeland [10] showed that a ring-current could be produced in the equatorial plane of a small magnetized model of the Earth. Brüche's experiments also showed that the presence of such a ring-current caused the incidence of aurora farther southward on the model of the Earth. A decrease in the current in this ring would then hardly be expected to cause the incidence of aurora farther southward as would be required on the basis of the hypothesis of Clay and Bruins.

T. H. Johnson [11], on the basis of observed changes in comic-ray intensity and in horizontal magnetic intensity, also estimated the radius of the assumed current-system proposed by Chapman [3] to be about four times that of the Earth for the magnetic storm near the end of April 1937. He cites the experiment of Brüche to indicate that a current-system of such a radius would be expected to cause an increase in cosmic-ray intensity. However, on three occasions a definite world-wide decrease

FIG. 1—COSMIC-RAY RECORDS, HUANCAYO, PERU, SHOWING EFFECT OF MAGNETIC STORM WHICH BEGAN 22^h.7 GMT, JANUARY 16, 1938

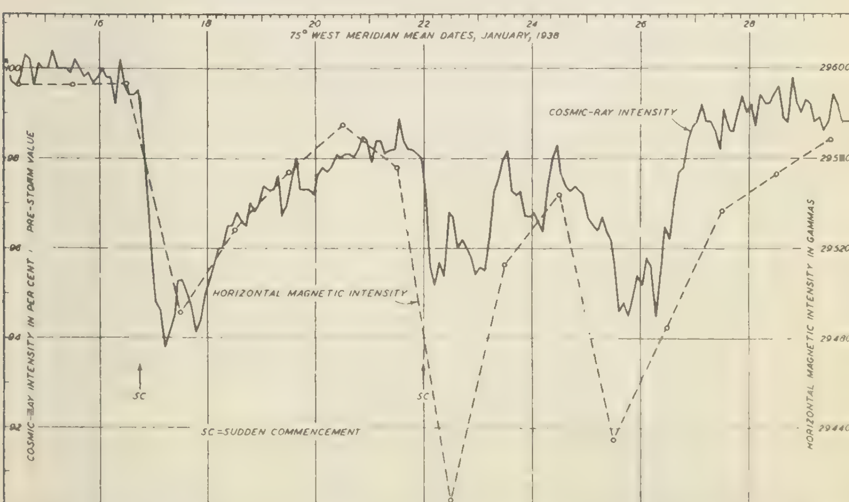

FIG. 2—MAGNETIC STORM-EFFECTS ON BIHOURLY MEAN COSMIC-RAY INTENSITY AVERAGED FOR BOSTON, UNITED STATES, CHELTENHAM, UNITED STATES, AND HUANCAYO, PERU, AND ON DAILY MEAN HORIZONTAL MAGNETIC INTENSITY, HUANCAYO, PERU

in cosmic-ray intensity was observed during the incidence of aurora in temperate latitudes. Whether both effects can be ascribed to a ring-current system can probably be decided only when the effects on cosmic-ray intensity for the field of such a ring have been calculated.

Results of observations on cosmic-ray effects during magnetic storms

From Compton-Bennett [12] precision recording cosmic-ray meters, operated, in a program for continuous registration, under the auspices of the Committee on Coordination of Cosmic-Ray Investigations of the Carnegie Institution of Washington, simultaneous cosmic-ray data have been obtained from two or more stations during three periods of intense magnetic storms. Cosmic-ray data used in this paper are corrected for barometric pressure [13] and were obtained from meters with a total shielding equivalent to 12 cm of lead.

Figure 1 is a reproduction of cosmic-ray records for four days obtained at the Huancayo Magnetic Observatory of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. Changes in barometric pressure during this period were small. The large increase in slope of the hourly electrometer-traces on the two lower records shows the effect of the magnetic storm which began at $22^h.7$, GMT, January 16, 1938.

The solid curve of Figure 2 indicates the changes in bihourly means of cosmic-ray intensity averaged for three stations. The dashed curve is drawn through the daily means of horizontal magnetic intensity for Huancayo. It will be noted that the ratio of changes in cosmic-ray intensity to those in horizontal magnetic intensity is greater for the interval January 17-21 than for the following period. This is also evident in Figure 3, which shows the agreement between changes in daily means of cosmic-ray intensity at three stations.

Figure 4 shows that the magnetic storm which began at $22^h.1$, 75° west meridian time, August 21, 1937, had no perceptible effect on cosmic-ray intensity at any one of the three stations indicated. The decrease in the daily mean of horizontal intensity from Agust 21-22 in Figure 4 is slightly greater than that from January 16-17 in Figure 3; otherwise, the changes in daily means of horizontal intensity for these two periods are very similar. If, during the interval January 16-21, 1938, the change in cosmic-ray intensity and that in horizontal magnetic intensity are both due to the magnetic field of the same current-system, then it follows that the current-system responsible for the changes in horizontal magnetic intensity from August 21-25, 1937, cannot be located at the same height above the Earth as that for January 16-21, 1938. That the type of current-system required to explain the decrease in horizontal intensity could certainly be similar in both cases will be shown later. From the greatly different effects on cosmic-ray intensity it appears impossible that the current-systems responsible for these two storms could both have been located within the Earth's atmosphere.

The proportionality, shown in Figure 6, between changes in daily means of horizontal magnetic intensity and in cosmic-ray intensity is an indication that one and the same current-system is responsible for both. That the ratios in Figure 6 of changes in cosmic-ray intensity to those in horizontal magnetic intensity are different also indicates that the

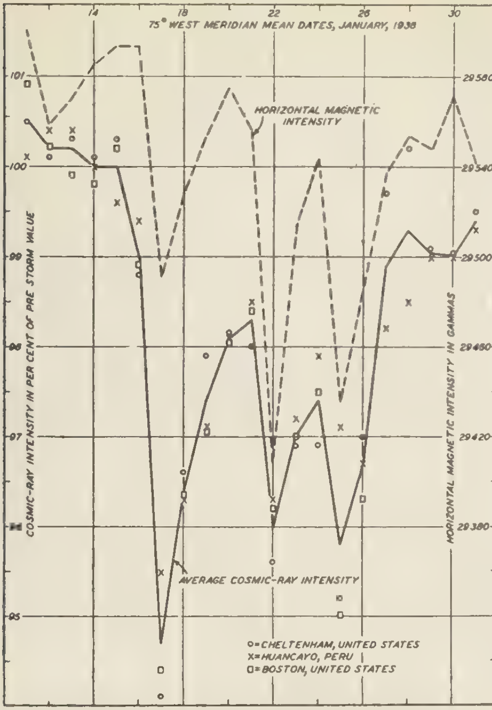

FIG. 3—MAGNETIC STORM-EFFECTS ON DAILY MEAN COSMIC-RAY INTENSITY AT BOSTON, UNITED STATES, CHELTENHAM, UNITED STATES, AND HUANCAYO, PERU, AND ON DAILY MEAN MAGNETIC HORIZONTAL INTENSITY AT HUANCAYO, PERU

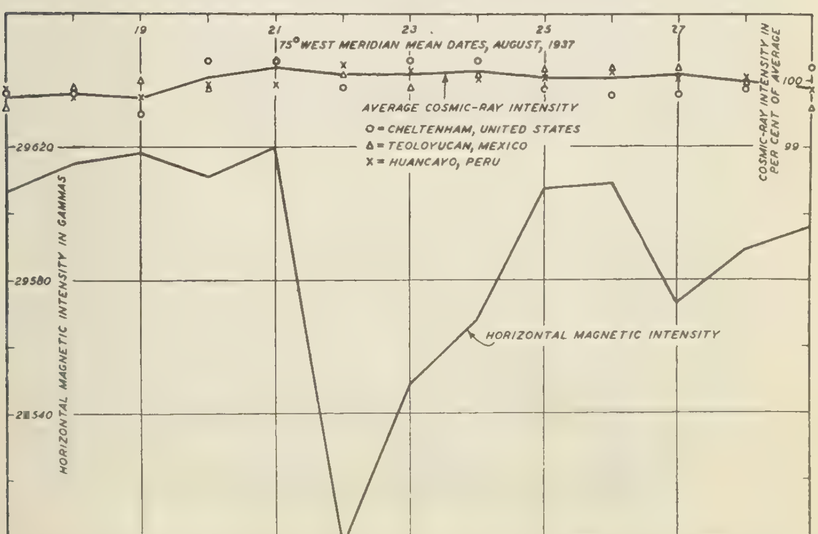

FIG. 4—DAILY MEANS HORIZONTAL MAGNETIC INTENSITY AT HUANCAYO, PERU, AND COSMIC-RAY INTENSITY AT CHELTENHAM, UNITED STATES, TEOLOYUCAN, MEXICO, AND HUANCAYO, PERU, SHOWING NO CHANGE IN COSMIC-RAY INTENSITY DURING MAGNETIC STORM BEGINNING AUGUST 21, 1937

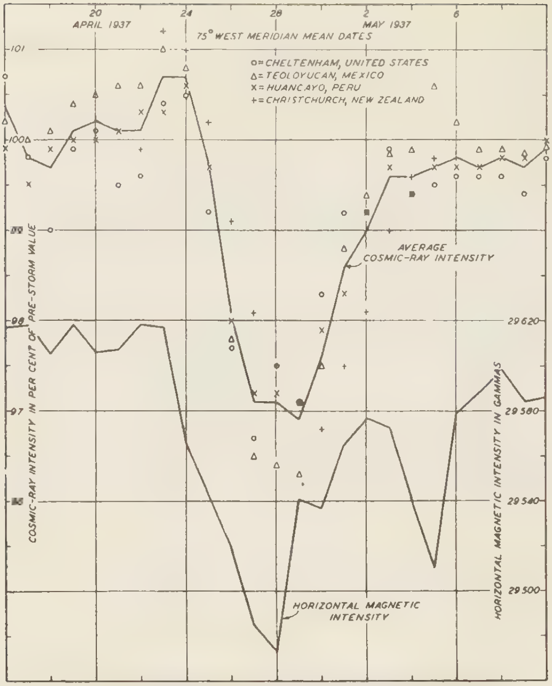

FIG. 5—MAGNETIC STORM-EFFECTS ON DAILY MEAN COSMIC-RAY INTENSITY AT CHELTENHAM, UNITED STATES, TEOLOYUCAN, MEXICO, HUANCAYO, PERU, AND CHRISTCHURCH, NEW ZEALAND, AND ON MAGNETIC HORIZONTAL INTENSITY AT HUANCAYO, PERU

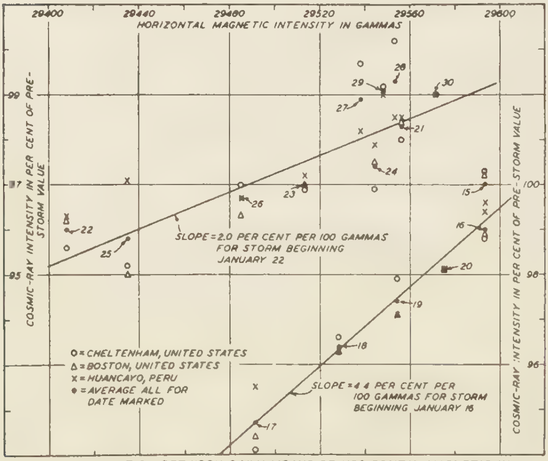

FIG. 6—CORRELATION BETWEEN DAILY MEANS OF HORIZONTAL MAGNETIC INTENSITY AT HUANCAYO, PERU, AND OF COSMIC-RAY INTENSITY AT BOSTON, UNITED STATES, CHELTENHAM, UNITED STATES, AND HUANCAYO, PERU, JANUARY 15-30, 1938

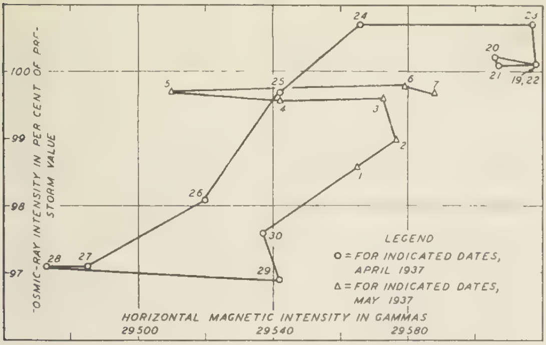

FIG. 7—RELATION BETWEEN DAILY MEANS OF HORIZONTAL MAGNETIC INTENSITY AT HUANCAYO, AND OF COSMIC-RAY INTENSITY AVERAGED FOR CHELTENHAM, TEOLOYUCAN, HUANCAYO, AND CHRISTCHURCH (DATA PER FIG. 5), APRIL 19 TO MAY 7, 1937

current-system responsible for these two storms flowed at different heights above the Earth.

Figure 5 shows the daily means of horizontal magnetic intensity at Huancayo and of cosmic-ray intensity at four stations during April 16 to May 10, 1937. While the correspondence between changes in cosmic-ray intensity at all the stations is evident, that between changes in cosmic-ray intensity and in horizontal magnetic intensity is not close. This is better shown in Figure 7, in which appear pronounced changes in horizontal magnetic intensity which are not accompanied by changes in cosmic-ray intensity. Magnetic records from Huancayo and Cheltenham showed sudden commencements on April 24, 25, 26, and May 4, 1937. These indicate the onset of what probably constitutes distinct magnetic storms. From Figures 5 and 7 it is evident that the first and last of these had no apparent effect on cosmic-ray intensity. The shape of the diagram in Figure 7 could be partially explained on the basis that the current-systems for the individual storms flowed at different distances above the Earth. The complete explanation of Figure 7 may involve the question of whether the current-systems for separate storms can simultaneously exist more or less independently.

Concerning the latitude-effect on changes in cosmic-ray intensity during magnetic storms

To determine whether a lattitude-effect is indicated in the changes of cosmic-ray intensity associated with magnetic storms there are plotted in Figure 8, for two periods of magnetic storms, daily means of cosmic-ray intensity at Huancayo and at Cheltenham. If the percentage-changes at Huancayo in geomagnetic latitude 0°.6 south and at Cheltenham in geomagnetic latitude 50°.1 north were equal, the points in Figure 8 should define the two lines with unit-slope. It is evident, however, that the scatter of points does not exclude the possibility of a latitude-effect of several per cent in the magnetic-storm effect.

This is also evident from Figure 9 in which is shown the high correlation ($r=0.89$) between departures from the average for the interval

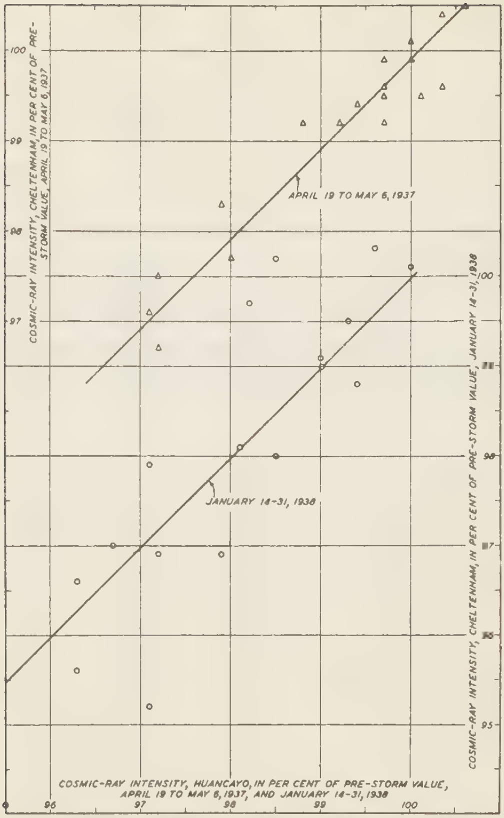

FIG. 8—CORRELATION BETWEEN DAILY MEANS OF COSMIC-RAY INTENSITY AT CHELTENHAM AND HUANCAYO FOR TWO PERIODS OF MAGNETIC STORMS, APRIL 19 TO MAY 6, 1937, AND JANUARY 14-31, 1938 (FOR NO LATITUDE-EFFECT POINTS WOULD DEFINE INDICATED LINES WITH UNIT-SLOPE)

April 23-30, 1937, of bihourly mean values of cosmic-ray intensity at Cheltenham and at Huancayo. The slopes of the two regression-lines are 1.11 and 0.88 The slope of the line defining the best value of the actual relation between departures at the two stations will lie between these two values, and will depend upon the relative weights assigned to the departures [14, 15]. If equal weight is assigned to both departures, the slope of the line is 0.98. On the basis of this series of data, which appears to be the better of the two in Figure 8, the possibility of the latitude-effect of several per cent is not excluded. The considerably greater scatter of points from the lower line in Figure 8 would allow a still larger latitude-effect. The difference in altitude between the two stations—72 meters at Cheltenham and 3350 meters at Huancayo—introduces further uncertainty concerning the latitude-effect for the same elevation. The effect of latitude on changes in cosmic-ray intensity during magnetic storms should be definitely answered when results are obtained from a Compton-Bennett meter now being installed at the Magnetic Observatory at Godhavn, Greenland, for the Committee on Coordination of Cosmic-Ray Investigations of the Carnegie Institution of Washington.

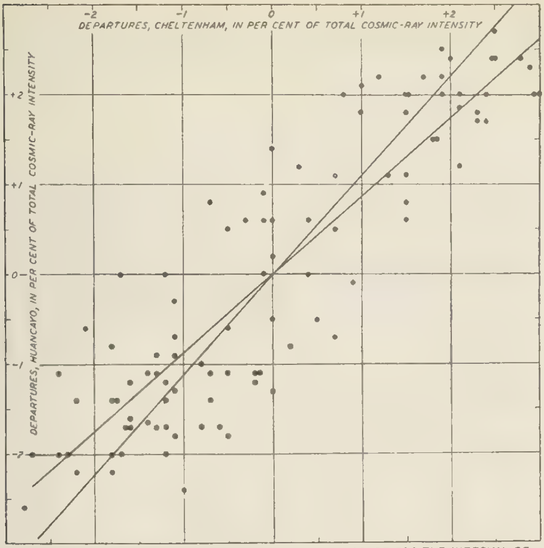

FIG. 9—CORRELATION BETWEEN DEPARTURES, FROM AVERAGE FOR THE INTERVAL, OF BIHOURLY MEANS OF COSMIC-RAY INTENSITY AT HUANCAYO AND CHELTENHAM, APRIL 23-30, 193' (REGRESSION-LINES INDICATED)

Comparison of the fields of the magnetic storms of August 21, 1937, and January 16, 1938

Since no discernible cosmic-ray effects were observed during August 21-24, 1937, and since the largest effects were observed between January 16 and 19, 1938, these two storm-periods were selected for further investigation. Changes in daily means of horizontal intensity at Huancayo for these two periods were closely similar indicating that the fields, at the Earth, of the two storms were about equally intense.

Table 1 gives, for each of these storms, the value, at six observatories, for each of the three geomagnetic components of the storm-field. The components for the storm-field, for groups A and B, were obtained in the usual way [2, 16] by subtracting from the daily mean values of the components of total intensity for days during the storm, those for selected magnetically quiet days.

To obtain the components of the storm-field for group C, values of the total-intensity components were averaged for five periods of eight hours, each centered at local midnight on one of the five selected quiet days used in groups A and B. For each of three successive local midnights, the second of which occurred at each observatory near 54 hours after the sudden commencement, average values of the components of total intensity were obtained for the eight-hour interval centered at local midnight. These averages for each component at each station, when plotted against time, fell very nearly on a straight line. From these lines were read off values for the components of total intensity 54 hours after the sudden commencement. From these were subtracted the values of the components of total intensity averaged for the midnight-intervals preceding the storm, to give the storm-field components in group C of Table 1.

The world-wide features of the storm-field depend on universal or storm-time and constitute what is generally called [2] the storm-time field. The horizontal component of the storm-time field at each station

Table 1—*Differences in intensity of geomagnetic components of Earth's field for selected days of sto minus selected quiet days preceding storm, for storms beginning August 21, 1937, and January 16, 1938*

Observatory	Geomagnetic coordinates			Group (see notes)	Intensity-differences					
					August 1937			January 1938		
	Φ	Λ	Ψ		North $\Delta X'$	East $\Delta Y'$	Down ΔZ	North $\Delta X'$	East $\Delta Y'$	Dow Δ
	°	°	°		γ	γ	γ	γ	γ	γ
Cheltenham, Maryland	+50.1	350.5	+ 2.4	*A*	− 70	+17	+ 6	− 92	− 2	+1
				B	− 30	0	+12	− 54	+ 1	+2
				C	− 28	− 1	+ 7	− 36	+ 1	+1
Tucson, Arizona	+40.4	312.2	+10 1	*A*	− 88	+16	+15	− 78	−10	+1
				B	− 38	− 4	+ 8	− 57	0	+1
				C	− 37	− 1	+ 9	− 48	− 4	+1
San Juan, Puerto Rico	+29.8	3.1	− 0.6	*A*	− 86	+14	+10	−100	+10	+1
				B	− 37	+ 2	+10	− 64	+ 8	+1
				C	− 40	0	+ 8	− 53	0	+1
Honolulu, Hawaii	+21.0	266.5	+12.3	*A*	−112	+12	+14	− 80	− 1	+
				B	− 42	+ 1	+ 2	− 60	+ 1	+
				C	− 50	+ 3	+ 7	− 57	− 3	+
Huancayo, Peru	− 0.6	353.8	+ 1.3	*A*	−110	+ 4	− 4	− 99	− 2	−
				B	− 48	− 3	+ 5	− 54	+ 8	−1
				C	− 46	0	+ 1	− 63	0	−
Watheroo, Western Australia	−41.8	185.6	+ 1.3	*A*	−102	+ 6	−39	− 76	−10	−1
				B	− 34	+ 3	−13	− 60	− 8	−1
				C	− 39	+ 4	−14	− 43	− 4	−1

Notes regarding groups:

A = mean for one day beginning six hours after sudden commencement of storm minus mean for five selected quiet days.

B for August 1937 = mean for two days beginning 30 hours after sudden commencement minus mean for five selected quiet days.

B for January 1938 = mean for two days beginning 22 and 54 hours, respectively, after sudden commencement minus mean for five selected quiet days.

C = value at 54 hours after sudden commencement obtained from linear adjustment through three eight-hour means centered at three successive local midnights minus average of eight-hour means centered at midnight on five selected quiet days.

is closely parallel to the geomagnetic meridians [16]. That the eastward components for group *C* in Table 1 are smaller than for the other groups suggests that the other components of the storm-time field in group *C* may more closely represent the actual components of the storm-time field than do those in groups *A* or *B*. It should be noted, however, that the components in group *A* pertain to the earlier and more intense part of the storm.

The storm-time field is very nearly symmetrical [16, 17] with respect to the geomagnetic equator so that if the eastward components in Table 1 are neglected a zonal harmonic series involving only harmonics of odd degree suffices to represent its magnetic potential. Because of the limited number of observatories for which data were immediately available for this analysis, the coefficients for harmonics of degree greater than three were disregarded. The expression of equation (1) was then assumed to represent the magnetic potential of the storm-time field.

$$V=[e_1r+i_1(a^3/r^2)]\,P_1+[e_3(r^3/a^2)+i_3(a^5/r^4)]\,P_3 \qquad (1)$$

in which a is the radius of the Earth and r is the distance from the Earth's center to the point at which the potential is to be evaluated. P_1 and P_3 are zonal-harmonic functions of the geomagnetic pole-distance; e and i

refer to the primary and induced systems, respectively. At the Earth's surface ($r=a$) the northward geomagnetic and vertical components are as given by equations (2) and (3).

$$\triangle X' = [(i_1+e_1)\, P'_1 + (i_3+e_3)\, P'_3] \qquad (2)$$

$$\triangle Z = [(-2i_1+e_1)\, P_1 + (-4i_3+3e_3)\, P_3] \qquad (3)$$

The primes in (2) denote derivatives with respect to geomagetic pole-distance.

By a least-square adjustment of the data for each of the groups in Table 1 the coefficients in (2) and (3) were determined. These are tabulated in the columns headed intensity in Table 2, in which the unit is one gamma $=10^{-5}$ gauss. Values of e_n and i_n are given in the columns headed potential.

TABLE 2—*Zonal-harmonic coefficients for differences in intensity for groups A, B, and C of Table 1 and for differences in intensity for international disturbed days minus international quiet days, 1927**

Storm	Group[a]	Degree n	Intensity		Potential		i_n/e_n
			North	Vertical	External e_n	Internal i_n	
			γ	γ	γ	γ	
Aug. 21, 1937	A	1	+113.7	+19.3	+82.2	+31.5	+0.38
		3	+ 1.9	−20.3	− 1.8	+ 3.7	−2.06
	B	1	+ 46.2	+16.7	+36.4	+ 9.8	+0.27
		3	0.0	+ 2.7	+ 0.4	− 0.4	−1.00
	C	1	+ 48.6	+11.4	+36.2	+12.4	+0.34
		3	− 0.2	− 8.4	− 1.3	+ 1.1	−0.85
Jan. 16, 1938	A	1	+102.0	+22.1	+75.4	+26.6	+0.35
		3	+ 6.8	+ 3.7	+ 4.4	+ 2.4	+0.55
	B	1	+ 66.8	+25.6	+53.1	+13.7	+0.26
		3	+ 6.8	− 0.9	+ 3.8	+ 3.0	+0.79
	C	1	+ 61.3	+20.3	+47.6	+13.7	+0.29
		3	− 1.1	− 4.7	− 1.2	+ 0.2	−0.17
Disturbed minus	D	1	+ 23.7	+ 3.8	+17.1	+ 6.6	+0.39
quiet days,		3	− 0.8	− 3.0	− 0.9	+ 0.1	−0.11
1927	E	1	+ 24.7	+ 4.0	+17.8	+ 6.9	+0.39
		3	+ 0.1	− 5.4	− 0.7	+ 0.8	−1.12

*Using data of Table 1 of L. Slaucitajs and A. G. McNish [16].

[a]Notes regarding groups: D = from adjustment two coefficients to data for stations with $\Phi \leqq 52°.5$. E = from adjustment Slaucitajs and McNish based on all data using four coefficients.

A, *B*, and *C* of Figure 10 indicate, respectively, the degree with which the observed components of the storm-time field are approximated by the series (2) and (3) for the groups of data *A*, *B*, and *C* of Table 1. The poor fit of points to the curves in *A* of Figure 10 is doubtless due to the effect of irregular disturbances superposed upon the storm-time field. The deviations of the observed points from the curves are less in *B* of Figure 10 and still less for *C* of Figure 10.

While there exists an infinity of current-systems, which could give rise to the observed storm-time field [2], we assume that the external current-system is in the form of an anchor-ring, the cross-section of which for mathematical convenience is assumed infinitesimal, concentric with

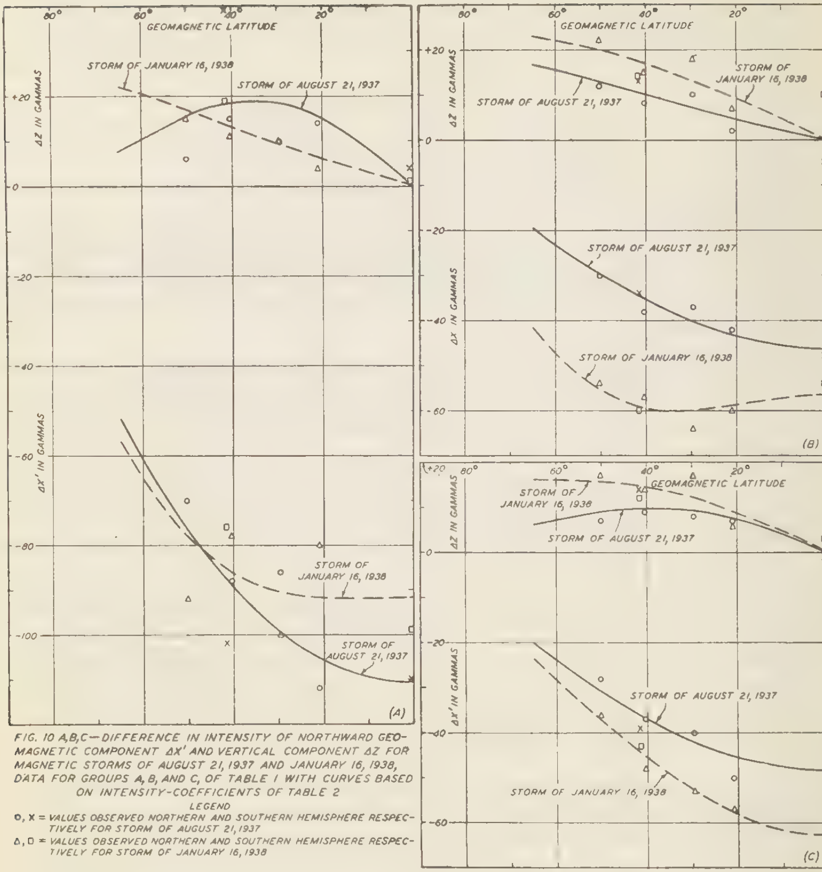

FIG. 10 A,B,C—DIFFERENCE IN INTENSITY OF NORTHWARD GEOMAGNETIC COMPONENT $\Delta X'$ AND VERTICAL COMPONENT ΔZ FOR MAGNETIC STORMS OF AUGUST 21, 1937 AND JANUARY 16, 1938, DATA FOR GROUPS A, B, AND C, OF TABLE 1 WITH CURVES BASED ON INTENSITY-COEFFICIENTS OF TABLE 2

LEGEND

o, x = VALUES OBSERVED NORTHERN AND SOUTHERN HEMISPHERE RESPECTIVELY FOR STORM OF AUGUST 21, 1937

Δ, □ = VALUES OBSERVED NORTHERN AND SOUTHERN HEMISPHERE RESPECTIVELY FOR STORM OF JANUARY 16, 1938

the Earth and in the plane of the Earth's geomagnetic equator. For such a ring, of radius R, in which flows unit westward current, the series for the magnetic potential, on the coordinate-system used in (1), at the surface of the Earth is given by equation (4), except for a constant.

$$V_R = 2\pi \left\{ (a/R)P_1 - (1/2)(a^3/R^3)P_3 + \ldots + (-1)^n \left[\frac{1\cdot 3\ \ldots\ (2n-1)}{2\cdot 4\ \ldots\ 2n}\right](a/R)^{2n+1}\, P_{2n+1} + \ \ldots \right\} \tag{4}$$

In (4) the ratio of the coefficient of P_1 to that of P_3 is $-2R^2/a^2$. In the case of the storms under discussion, if the only source of potential were the assumed ring-current, $\sqrt{-e_1/2e_3}$ should determine R/a, the radius of the assumed ring in terms of the Earth's radius a.

However, the rather concentrated westward currents [2] in the auroral zones give rise to another source of potential. If the two zones, in each of which flows a westward current i, are considered as two circles of geomagnetic latitude on a sphere, concentric with the Earth and of radius c, and if the radius of each circle, one in the Northern and the other in the Southern Hemisphere, subtends an angle α at the Earth's center, then the potential of the system [18] for points on the Earth between the zones is, except for a constant, given by

$$\Omega = 4\pi i \sin^2\alpha \sum_{n=1}^{n=\infty} (1/n)(a^n/c^n)P'_n(\alpha)P_n \quad \ldots \text{ for } n \text{ odd and } a<c \qquad (5)$$

P_n is the zonal-harmonic function of geomagnetic pole-distance and $P'_n(\alpha)$ its derivative with respect to the cosine of pole-distance. When α and i in (5) are known, the coefficients for P_n in (5) can be determined. Subtracting these from the coefficients e_n given in Table 2, we have the coefficients for the potential of the assumed equatorial ring-current alone.

During the period from which the data in Table 1 for group C of the January storm were obtained, the character of the diurnal variations of vertical and horizontal magnetic intensity at Sitka indicated that the zonal currents flowed close to, but north of, that station. For the two-day interval centered 54 hours after the sudden commencement of the storm of January 16, 1938, daily means of horizontal intensity, H, and vertical intensity, Z, were computed for Sitka and from them the corresponding means for the five quiet days preceding the storm were subtracted. These vertical and horizontal components of the storm-time field fell respectively 30 gammas and 40 gammas below the values for $\triangle Z$ and $\triangle X'$ given by the curves at $\Phi = 60°$, for the storm of January 16, 1938, in C of Figure 10. The vertical and horizontal components of the field of the zonal current at Sitka may then be taken as 30 and 40 gammas, respectively. Assuming the zonal current to be linear at a height of 150 km, the horizontal distance S from Sitka to a point directly beneath the current is given by $S = 150 \times (40/30)$ or 200 km. The field of the current at a distance of 250 km is 50 gammas, which gives about 62,000 amperes for the zonal current. This is not very different from the value estimated by Chapman [2] for the total westward current in the auroral zone during moderate storms.

Thus at the time of the storm of January 16, 1938, to which group C of Table 2 applies, we estimate the westward zonal current in the northern and southern zones, in geomagnetic latitude 62°, to be 62,000 amperes. This estimate may also be safely used for group B for the storm of January 16, 1938. For group C of the August storm, the zone was too far north of Sitka to permit a reliable estimate of its location. We shall perhaps be not far wrong in assuming the geomagnetic latitude of the zones to be 70° and the current to be about 40,000 amperes, since the value of e_1 in Table 2 for group C for the storm of August, 1937, is about three-fourths of that in group C for the January storm. Similarly, for groups D and E, we adopt 70° for the latitude of the zones and 20,000 amperes for the current.

Using these data the coefficients of P_1 and P_3 in equation (5) are calculated. These are designated, with signs changed, in Table 3 as corrections, $\triangle e_n$, which are applied to the values of e_n in Table 2. E_n of

Table 3 thus gives the values of the coefficients which are ascribed to the field of the assumed equatorial ring-current.

In Table 3 it should be noted that all values of E_3 are negative, which according to equation (4) is a necessary condition for the existence of an equatorial ring carrying a westward current.

Unfortunately the values of (R/a) in Table 3 provide no convincing evidence concerning the important question of whether the radius of the assumed equatorial ring-current is, as would be expected, greater for the storm of January 16, 1938, which resulted in a large decrease in cosmic-ray intensity. However, it can be safely said that for none of the storms could (R/a) have been much less than two. In an unpublished manuscript, Dr. E. H. Vestine, of the Department of Terrestrial Magnetism, using the results of the analysis by L. Slaucitajs and A. G. McNish [16], finds, by a somewhat different procedure, a value between two and four for (R/a).

The method used here would of course be more effective the smaller the values of (R/a). The analysis is presented in the belief that the results may prove useful in checking future theories concerning the orbits of cosmic-ray particles in the field of a magnetic storm superposed on the Earth's permanent field.

Table 3—*Corrections Δe_n to coefficients e_n for the potential in Table 2 on account of estimated currents i flowing westward in two zones in equal north and south geomagnetic colatitudes α and estimated radius (R/a) of assumed equatorial ring-current in earth-radii*

Storm	Group	Degree n	α	i	Δe_n	e_n	$E_n = e_n + \Delta e_n$	$-(E_1/2E_3)$	(R/a)
			°	amp	γ	γ	γ		
Aug. 21, 1937	*B*	1	20	4.0×10^4	−0.9	+36.4	+35.5	16.2	4.0
		3			−1.5	+ 0.4	− 1.1		
	C	1	20	4.0×10^4	−0.9	+36.2	+35.3	6.3	2.5
		3			−1.5	− 1.3	− 2.8		
Jan. 16, 1938	*B*	1	28	6.2×10^4	−2.7	+53.1	+50.4	252.0	15.8
		3			−3.9	+ 3.8	− 0.1		
	C	1	28	6.2×10^4	−2.7	+47.6	+44.9	4.4	2.1
		3			−3.9	− 1.2	− 5.1		
Disturbed minus quiet days, 1937	*D*	1	20	2.0×10^4	−0.5	+17.1	+16.6	4.9	2.2
		3			−0.8	− 0.9	− 1.7		
	E	1	20	2.0×10^4	−0.5	+17.8	+17.3	5.8	2.4
		3			−0.8	− 0.7	− 1.5		

Evidence for world-wide effects on daily means of cosmic-ray intensity

That the daily means of cosmic-ray intensity at two widely separated stations are influenced in part by a common cause is indicated in Figure 11. To investigate the possible influence of solar rotation upon cosmic-ray intensity it was convenient to take averages of daily means of cosmic-ray intensity for alternate periods of four and five days. The correlation between the first differences of these (each average minus the preceding one) is shown in Figure 11. Data for days near the end of April 1937, on which the cosmic-ray intensity was definitely known to be affected by magnetic storms, were not included in deriving the correlation. After allowing for the fact that, at most only half of the 81 differences plotted

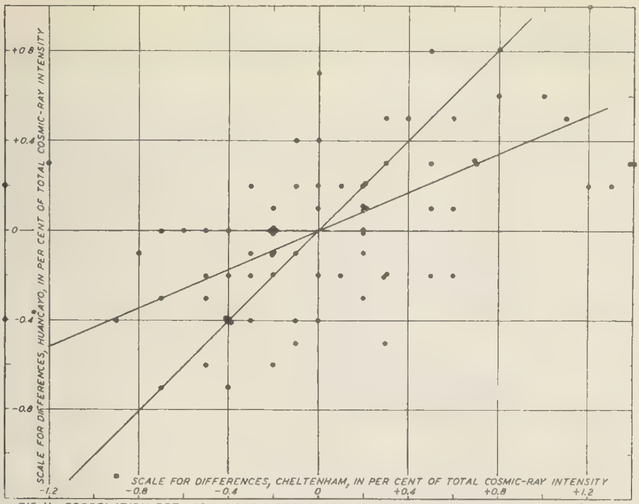

FIG. 11—CORRELATION BETWEEN FIRST DIFFERENCES, FOR CHELTENHAM AND HUANCAYO, OF AVERAGE COSMIC-RAY INTENSITY FOR CORRESPONDING ALTERNATE INTERVALS OF 4 AND 5 DAYS, JUNE 13 TO OCTOBER 2, 1936, AND APRIL 6 TO DECEMBER 31, 1937, EXCLUDING DAYS AFFECTED BY MAGNETIC STORM OF APRIL 1937 (REGRESSION-LINES INDICATED)

in Figure 11 are statistically independent, the moderate correlation ($r=0.64$) indicates a significant correspondence. That a line with unit-slope, as for Figure 8, through the origin in Figure 11 lies between the two indicated regression-lines is further indication that the correspondence is not accidental.

Whether the changes in daily means of cosmic-ray intensity at Huancayo and at Cheltenham are definitely associated with changes in the Earth's magnetic field due to minor magnetic disturbances is not yet certain.

Preliminary investigation of the 27-day period suggests the possibility of quasi-persistent [19] 27-day waves in cosmic-ray intensity having similar phases at Cheltenham and Huancayo. This would indicate, because of the 27-day quasi-persistent wave [19] in magnetic activity, that the mechanism responsible for the correlation in Figure 11 is the same as that for the world-wide changes observed during some magnetic storms.

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We are under obligation to the Director of the United States Coast and Geodetic Survey for making available to us the magnetic data from its five magnetic observatories and also to the staff of its Cheltenham Magnetic Observatory for operation of a cosmic-ray meter. We are also indebted to J. W. Beagley, of the staff of the magnetic observatory at Christchurch, New Zealand, for operation of a meter and reduction of

records at that station, to Professor J. Gallo, Director of the National Astronomical Observatory at Tacubaya, Mexico, for supervising the operation of the cosmic-ray meter at Teoloyucan, to the staff of the Huancayo Magnetic Observatory of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington for operation of a meter, to Professor R. D. Bennett of the Massachusetts Institute of Technology for making available to us the cosmic-ray records obtained there during the magnetic storm of January 1938, and to the National Carbon Company, Incorporated, for providing all batteries for operating the meters.

Finally, it is a pleasure to acknowledge the encouragement received from Dr. J. A. Fleming, Director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington.

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ON THE DIURNAL VARIATION OF THE MAGNETIC POLE

By K. F. Wasserfall

Introduction—When Roald Amundsen planned his Expedition with the *Gjöa* he studied the practical side of the earthmagnetic science at the Observatory at Potsdam, where Ad. Schmidt acted as his chief tutor. Professor Schmidt was personally very interested in this Expedition, especially because it offered the rare opportunity to obtain magnetic observations suitable for fixing the geographical coordinates of the magnetic pole.

For use during the Expedition Schmidt provided Amundsen with written instructions, which have been published in part in the magnetic results of the Expedition [see 1 under "References" at end of paper]. Here Schmidt writes: "For an approximate calculation we may accept the following values for the magnetic elements at the surface of the globe in the neighborhood of the magnetic north-pole: Vertical intensity, $V=62000\gamma$; inclination, $I=90°-0'.5\alpha$, at a distance of α miles from the pole; horizontal intensity, $H=9\times\alpha\gamma$ at a distance of α miles from the pole (one mile = 1.852 km). Thus we may, with sufficient accuracy, calculate horizontal intensity by aid of inclination or *vice versa*, since to each minute by which the inclination is less that 90°, corresponds 18γ, in the horizontal intensity, and we have accordingly Table 1.

Table 1

α	10	30	60	120	240
	° ′	° ′	° ′	° ′	° ′
I	89 55	89 45	89 30	89 00	88 00
H	90γ	270γ	540γ	1080γ	2160γ

"The accuracy of the observation of declination can be estimated as follows: Approximately, up to a distance of 100 miles from the pole, or perhaps more, the declination-needle points in the direction of the magnetic pole, provided no local disturbance deflects the needle or no considerable perturbation is just going on. Furthermore it must be remembered that a variation of 1′ in declination corresponds to $H/3438\gamma$, which means about $\alpha/400\gamma$ at a distance of α miles from the pole. In other words, at a distance of 400 miles a variation of 1′ in declination corresponds to 1γ.

"The pole itself is of course perpetually moving about. This movement may, however, be said to be limited to a movement about a fixed geographical point, which represents the main position of the pole. To obtain material suitable for fixing the geographical coordinates of this point may be said to be the great aim of the Expedition.

"During time of perturbation the pole may vary from the main position by a distance of at least 50 miles and under certain circumstances the distance may even go up to 100 miles. Thus we may not expect the pole-of-the-moment to be found within a radius of ten miles from the main point for more than 50 days out of 100.

"If it is possible, the base-station ought to be put at a place where the inclination is about 89°, or where the horizontal intensity is about 1000γ, which corresponds to a distance from the main pole of about 120 miles. In any case the base-station ought not to be placed closer towards the pole than 100 miles."

Mean values for the magnetic elements at Gjöahavn during the year 1904—The geographical coordinates for Amundsen's magnetic station at Gjöahavn were: Latitude, $\phi=68° 37' 38''$ north; longitude, $\lambda=95° 54' 51''$ west. Monthly values for the elements during the year 1904 are stated in Table 2.

Table 2

Month	D, west	I, north	H	X	Y	Z
	°	° ′	γ	γ	γ	γ
Jan.	8.7	89 18.1	737	729	111	60286
Feb.	8.9	89 17.4	750	741	116	60273
Mar.	8.2	89 16.9	758	750	108	60266
Apr.	7.9	89 16.9	758	751	104	60276
May	7.7	89 16.5	765	758	102	60261
June	7.0	89 16.0	774	768	94	60258
July	6.6	89 15.6	781	778	90	60268
Aug.	6.2	89 16.3	769	765	83	60258
Sep.	6.5	89 16.6	764	759	86	60250
Oct.	6.7	89 16.6	764	759	89	60264
Nov.	6.9	89 17.0	755	750	91	60262
Dec.	6.9	89 17.0	755	750	91	60235
1904	7.4	89 16.7	761	755	97	60263

The magnetic pole—Gauss defines the magnetic pole as a place where the value of the horizontal intensity is equal to zero. At such a place the inclination-needle points vertically and, as there does not exist any directive force, the declination-needle may point in whatever direction it is placed.

During the three months March to May, 1904, Amundsen made a sledge-expedition to Boothia Felix, with the purpose of making magnetic observations in the neighborhood of the place, where in 1831 James Ross had located the magnetic pole. Unfortunately, circumstances prevented Amundsen from carrying out his plan to the extent previously formed, so that the number of stations is very small. However, as the quality of the data collected is excellent, it seems probable that the following coordinates are fairly well founded:

Amundsen's magnetic pole of 1904.5: $\phi=70° 30'$ north, $\lambda=95° 30'$ west.

James Ross's magnetic pole of 1831: $\phi=70° 05'$ north, λ 96° 46′ west.

On the diurnal variation of the pole—Before the final results of the *Gjöa* Expedition could appear in print Graarud and Russeltvedt published a preliminary summary [2]. In this paper the authors have tried to give an idea of the geographical variation of the magnetic pole in relation to the main position stated above. This "*perpetually moving about*" of the pole-point was, as we remember, predicted by Schmidt.

The material employed to show the variation of the pole is to be found in Table 3 for diurnal variation of D and H at Gjöahavn, on the following

line of reasoning: From the data stated in Table 3 we see that the diurnal variations of D and H are very pronounced. It is to be supposed that the diurnal variation of the pole is to be had in figures by multiplying these variation-data for D and H by constants directly dependent on the distance between Gjöahavn and the main pole-point, as fixed above.

TABLE 3

Hour	D	H	Hour	D	H
	°	γ		°	γ
1	2.5	−16.1	13	−2.1	20.1
2	2.8	−10.6	14	−2.7	15.6
3	2.7	− 5.6	15	−3.1	7.2
4	2.7	− 1.3	16	−3.4	− 2.3
5	2.6	2.4	17	−3.2	− 8.2
6	2.3	10.4	18	−2.7	−11.4
7	1.6	17.6	19	−2.1	−11.1
8	1.1	19.9	20	−1.0	−18.8
9	0.2	22.8	21	−0.1	−24.9
10	−0.5	22.3	22	0.9	−28.5
11	−1.0	22.4	23	1.6	−24.6
12	−1 4	22.9	24	2.2	−20.1

Now this distance is 394.5 miles or 213 km. The mean value for H at Gjöahavn for 1904 is 760γ (compare Table 2). Thus the required constant for the H-data should be $213/760=0.28$. At a distance of 213 km one degree corresponds to 0.062 km and consequently we have for the constant for the D-data, 3.72. Now plotting the H- and D-data as in Figure 1, we see that the diurnal variation of the pole takes the shape of an oval of about 22 km in the direction east to west and about 14 km in the direction north to south. The figures 1 to 24 marking the small open circles represent the hour of the day for each special location of the pole in relation to the main point.

Discussion—As far as I can see the above results and the reasoning

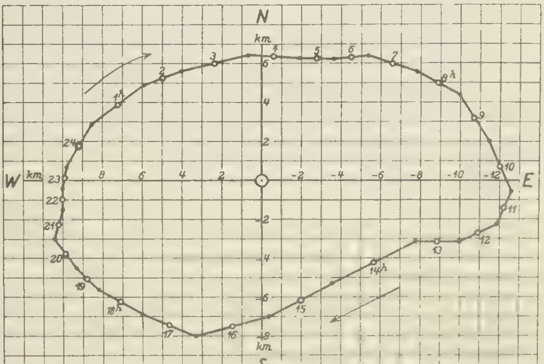

FIG. 1—DIURNAL TRACK OF THE NORTH MAGNETIC POLE ACCORDING TO LOCAL MEAN TIME

leading to them are wholly in agreement with what Schmidt predicted. The results have also been accepted by Nippoldt, who in one of his papers [3] gives a reproduction of above figures and writes: "Bei der Festlegung des Ortes aus Beobachtungen ist zu bedenken, das der Pol infolge der zeitlichen Variationen innerhalb eines gewissen Bereichs dauernd wandert. So haben die Variationsbeobachtungen Amundsens dargetan, dass allein infolge der täglichen Variation von dem nördlichen Pol ein Oval von rund 22 km in Länge und 14 km in Breite durchlaufen wird."

Neither Schmidt, nor Nippoldt attempts to explain the phenomena physically. According to what has been stated above, there seems to be no doubt that the observed data indicate a diurnal variation of the magnetic pole in agreement with what has been shown in Figure 1 and the physical explanation is probably that the diurnal variation of the magnetic elements is dependent on electromagnetic current-systems situated in the ionized part of the atmosphere. It seems, therefore, reasonable to base the discussion on the dynamo-theory, developed by Schuster, Chapman, and Bartels, as formerly done in the discussion of the diurnal variation of the Dombås material [4].

The main point in the discussion was as follows: If the quiet diurnal variation of magnetic elements were due to the existence of an electromagnetic current-system situated in the ionized part of the atmosphere, there ought to be a characteristic relation between the variation of the H-data and that of the D-data. Furthermore, the time at which the extremes and the zero-point passage in the diurnal variation of D and H occur should agree with that derived from the idealized current-system constructed by Chapman and Bartels [see 4, p. 7].

In reference [4] it was shown that such agreement between the observed data, and those derived from theory, actually existed. Not only was this agreement found for the material discussed for Dombås but also for corresponding data for the two stations Tromsö and Rude Skov. For stations with high absolute value for declination it was shown that the parallelism in the phases of the waves was disturbed so that the phases were displaced in a direction toward earlier local time according to increasing westerly declination. However, this displacement could be eliminated if, instead of D and H, the Y- and X-components were used.

To determine whether the above-mentioned agreement in the quiet diurnal variation of D and H actually exists for the material collected by Amundsen at Gjöahavn, data for the quiet-day variation for D, H, and Z have been computed according to methods described in the publication giving the results for Dombås for the interval 1916-33 [5]. Mean monthly curves for the quiet diurnal variation in D, H, and Z at Gjöahavn are plotted in Figure 2.

As the absolute value of declination is small both at Dombås and at Gjöahavn—8° 30′ west and 7° 25′ west, respectively—there ought to be almost no displacement in the phases and direct agreement in local time between extremes and zero-passages in the observed curves and the time derived from theory should be found. Looking at the curves in Figure 2 we see that the parallelism between Dombås and Gjöahavn is pronounced at least for H. The agreement in time is especially good for minimum and also for the two zero-point passages. Regarding maximum in H we see that both stations show a chief maximum point and a secondary one but here occurs a characteristic disagreement between

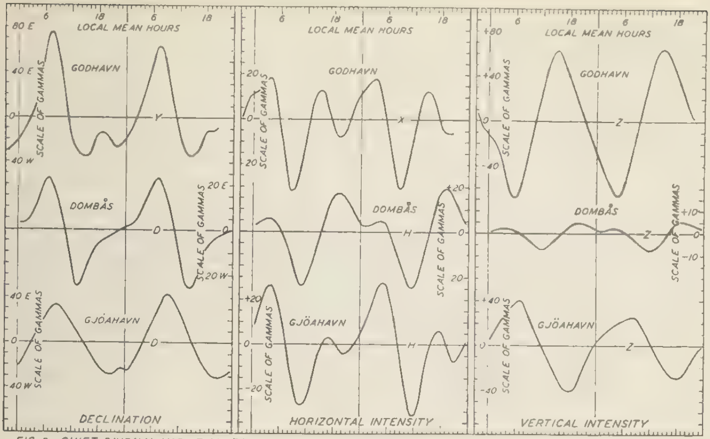

FIG. 2—QUIET DIURNAL VARIATION FOR DECLINATION, HORIZONTAL INTENSITY, AND VERTICAL INTENSITY FOR JUNE AND JULY

the two stations, namely, Dombås has its chief maximum at about $19^h\ 30^m$ and the secondary one at about 4^h. At Gjöahavn, however, the maximum at 4^h is the principal, while the other, at about $16^h\ 30^m$, is the secondary. Looking at the curves for D, we find good agreement also in time as regards the eastern extreme, while the form of the variation during the interval 14^h until about 4^h in the morning is strangely different for the two stations. As to the form of the quiet diurnal variation of the Z-component we find almost no parallelism. As, however, the variation in this component is only of secondary interest in connection with the current-system theory [compare 4], it is not worth while to discuss it here.

In our discussion [4] we chose the Danish station Godhavn (Greenland) ($\phi = 61°\ 14'.4$ north, $\lambda = 53°\ 31'.3$ west) as an example showing the above-mentioned displacement of the phases in the variation caused by high absolute value for declination ($D = 57°\ 20'$ west). For this station we found fairly good parallelism also in the form of the variation when compared with the curves for the Scandinavian stations. The points of time, when the extremes occur, as well as the zero-passage at about 11^h agree well, when the D-data are replaced with the Y-data. However, the form of the variation between 14^h and about 4^h shows a disagreement when compared with the Scandinavian stations; this disagreement proves to be more or less of the same character as that mentioned above for the D-data at Gjöahavn. The X-curves for Godhavn show also some characteristic features, which do not agree with corresponding curves for the Scandinavian stations.

In order to get a good view of the nature of the variation in the quiet diurnal curves for the three stations Godhavn, Dombås, and Gjöahavn – both regarding the features where there is agreement and during the hours when a characteristic disagreement occurs—I have plotted in Figure 3 comparable curves for D, H, and Z for the two summer months June and July. For reasons given above the Y- and X-curves are used for Godhavn instead of those for D and H.

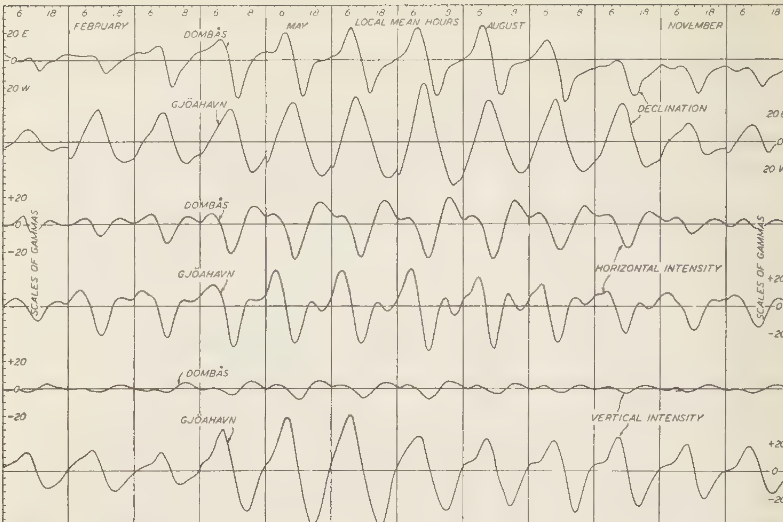

FIG. 3—MONTHLY MEAN VALUES FOR QUIET DIURNAL VARIATION AT DOMBÅS, 1933, AND AT GJÖAHAVN, 1904

To facilitate the comparison as regards the point of time for the various important occurrences, I have compiled Table 4, giving times for the occurrences as indicated. Table 4 is divided into an upper part dealing with the *D*-data and a lower part dealing with the *H*-data. Since—according to theory—time for one zero-passage of the element ought to correspond to time for the extremes of the other element, such data are placed directly below each other. Under the heading "Station" I have also entered "Theory," the hours for which in the various columns indicate the point of time when the occurrences under the headings in question actually ought to take place, as derived from the graph for the idealized current-system [compare 4, p. 7].

Table 4

From	Station	Max. *E*	Zero *Z*,1	Max. *W*, 1	Max. *W*, 2	Zero *Z*, 2
		h m	h m	h m	h m	h m
D	Theory	7 00	10 30	13 14	.. ..	20 22
	Godhavn	7 30	11 00	15 00	23 30	2 00
	Dombås	7 00	10 30	12 30	.. ..	22 30
	Gjöahavn	8 30	14 30	20 00	1 30	4 00

From	Station	Max. 1	Zero *Z*, 1	Min. 1	Zero *Z*, 2	Max. 2	Min. 2
		h h	h h	h m	h m	h m	h h
H	Theory	2 to 6	6 to 7	10 30	15 00	.. ..	2 to 6
		h m	h m				h m
	Godhavn	4 00	5 30	8 30	12 30	15 00	19 00
	Dombås	4 00	6 30	10 30	15 00	19 30	1 00
	Gjöahavn	4 00	7 30	10 30	15 30	16 30	20 00

The occasional disagreement between theory and observation-especially at Godhavn and at Gjöahavn during the interval 14^h to 4^h may be due perhaps to difficulty in deciding if a value during this interval is to be considered undisturbed or disturbed. However, the disagreement may also be real and may be caused by the particular geographical situation of these two stations. The fact that the form of the variation during these hours has a certain similarity at both stations seems to favor this reasoning.

Conclusion—As a conclusion from Table 4 we may probably infer that the fairly satisfactory agreement between theory and observation supports strongly the Chapman-Bartels theory that there exists an electromagnetic current-system in the ionized part of the atmosphere and that this current-system is responsible for the main features of the quiet diurnal variation of the magnetic elements—even for stations situated in the immediate neighborhood of the magnetic pole. According to what has been shown in Figure 1 we may also conclude, that the diurnal variation of the magnetic pole is caused by this current-system.

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NOTES

(See also pages 244 and 342)

26. *Wilhelm Filchner's Expedition in Asia*—Some further details regarding the last expedition of Dr. Wilhelm Filchner, 1934-38 (see this JOURNAL, **42**, 429, 1937) have been published in the July 1938 number of the London *Geographical Journal.* The principal object of this second Expedition was to complete the magnetic picture of Central Asia. All the instruments were compared both before and after the field-work with the standards of Potsdam and Dehra Dun. The Expedition was planned for two years but, owing to accidents and misfortunes, four years passed before its completion. At points where it was possible to remain for any length of time a network of observations covering small areas was made using the Schmidt balance.

"The results of this second Expedition have made it possible to extend the linear distribution of results to a more complete areal distribution, and it is now possible to make a magnetic map of the area comprising Tashkent, Urumchi, Kaolan, and Lhasa. The results of these two expeditions have also a practical value for aerial navigation, as well as for engineering and mining."

Some 520 magnetic stations were occupied in the course of these two expeditions of 1926-28 and 1934-38, of which 360 belong to the latter. The reduction of the magnetic data is now being made by Professor O. Venske, of Potsdam.

27. *Intercomparisons of instruments at Batavia, Java*—W. C. Parkinson, of the Department of Terrestrial Magnetism of the Carnegie Institution, having completed an extensive program of magnetic field-work in Malaya, Siam, and Indo-China, stopped at Batavia, Java, on his return journey to the Watheroo Magnetic Observatory, to compare his field-instrument, magnetometer-inductor 28, with the standards of the Royal Magnetical and Meteorological Observatory. At the same time he compared magnetometer-inductor 13 which had been sent to China for continuing magnetic survey-work there. Unfortunately it was found impossible at present to undertake such work in China. After the comparisons were completed at Batavia, magnetometer-inductor 13 was shipped to Dr. A. Walter, Director of the British East Africa Meteorological Service where it is to be used for securing magnetic observations at stations of that Service.

28. *Highest value of magnetic horizontal intensity observed by the Department of Terrestrial Magnetism*—On March 25, 1938, W. C. Parkinson, while at Chumphon, Siam (latitude 10° 30′.7 north, longitude 99° 10′.8 east) obtained a value of 40759 gammas for H. The corresponding value for D was 0° 23′.2 east, and for I, 2° 51′.6 north. From former observations of the Department in the same general region in 1912, at Bangkok and Huahin, the average annual variation between 1912 and 1938 is found to be +23 gammas at Bangkok and +31 gammas at Huahin. It is interesting to note that the world isoporic chart for H, prepared by H. W. Fisk, indicates this region to be near a prominent focus of *increasing* H. As is well known, over most of the Earth's surface H is *decreasing.*

BURSTS IN COSMIC RADIATION IN THE EQUATORIAL ZONE

By S. A. Korff

Abstract—Bursts in cosmic radiation observed in Peru and in northern latitudes are compared. It is found that the bursts have the same distribution in energy both at high altitudes in the equatorial zone and at sea-level in northern latitudes. The number of bursts is found to vary approximately as the third power of the number of ions in the burst. The number of bursts increases with altitude approximately as the square of the total ionization measured in the same instrument. Bursts are found to produce about one part in 1000 of the ionization observed in the instrument.

In the course of a program of measurements for comparing the various cosmic-ray meters of the Carnegie Institution of Washington, 709 bursts in the intensity of the ionization due to cosmic radiation were noted. These bursts have been analyzed with regard to their distribution in energy, with a point of inquiring how this characteristic varies with altitude and latitude. In the equatorial zone, primary rays of less than about 1.5×10^{10} electron-volts are excluded by the Earth's magnetic field. The question arises whether this difference in the character of the primary radiation will result in a different size-distribution of the bursts.

Studies of the variation of bursts with altitude have been carried out in northern latitudes by C. G. and D. D. Montgomery [see 1 under "References" at end of paper] and by Bennett, Brown, and Rahmel [2]. Messerschmidt [3] has investigated the dependence of bursts on the nature and thickness of the material used in shielding the measuring chamber.

Instrument and stations—In the present investigation, three electroscopes of the type described by Millikan and Neher [4] were used. These consist of a quartz-fiber electroscope in a bomb 15 cm in diameter. The bomb is filled with argon to a pressure of 30 atmospheres. The instruments are equipped with a lead shield 10 cm thick, inside a 12.5-mm iron shell, giving an equivalent shielding of 11 cm of lead.

Bursts appear as abrupt discontinuities on the record made by the discharging needle of the electroscope. The length of the discontinuity is proportional to the number of ion-pairs in the burst. The factor of proportionality has been determined for each instrument by Millikan. Table 1 summarizes the number of bursts recorded at three widely distributed stations. The figures of Table 1 refer to the actual numbers of ion-pairs collected in the burst without reduction to standard pressure, and are to be compared with a normal sea-level ionization of 8.3×10^4 ions per second in the same instrument.

A lower limit to the size of a measurable burst is established by the finite width of the trace and by the film-speed. Probable fluctuations in the ionization due to the finite number of single rays passing through the instrument in the smallest measurable time are, according to the analysis of Evans and Neher [7], of the order of one-tenth the size of the smallest burst recorded.

The instruments were operated at Kensington, Maryland, United States (elevation 100 meters, geomagnetic latitude 51° north), at Huancayo, Peru (elevation 3340 meters, geomagnetic latitude 1° south), and at Ticlio, Peru (elevation 4780 meters, geomagnetic latitude 0°).

Observations—The magnitudes of the bursts were between 3×10^6 and 36×10^6 ions each. No burst larger that 36×10^6 ions occurred during the entire period. Bursts smaller than 3×10^6 ions cannot be measured with accuracy with this instrument. During the period of 427 instrument-days, a total of 709 bursts were recorded. Of these, 16 were between 15×10^6 and 36×10^6 ions each and were classified as "very large."

Table 1—*Summary of all bursts observed at various altitudes and latitudes, classified to show distribution in energy*

Energy of burst	Number observed at Kensington	Huancayo	Ticlio
ion-pairs $\times 10^6$			
2.8- 4.3	220	81	
4.3- 5.8	124	62	6
5.8- 7.3	35	5	2
7.3- 8.8	51	23	4
8.8-10.3	31	8	1
10.3-11.8	6	1	3
11.8-13.3	8	5	5
13.3-14.8		1	2
14.8-16.2	6	3	4
16.2-30.2	6	7	
30.2-44.2	2	1	
Total bursts recorded	489	197	23
Instrument-days	383	38	6
Mean barometer in mm	750	515	426
Elevation in meters	100	3340	4570
Geomagnetic latitude	51°N	1°S	0°

All the bursts observed at the various stations are presented in Table 1 and are classified in groups according to energy. At Kensington, 489 bursts took place in 383 instrument-days, or an average of 1.28 bursts per day. At Huancayo, there were 197 bursts in 38 days, or 5.2 bursts per day, a rate of occurrence 4.05 (± 0.1) times as great as it was at Kensington.

The total ionization at Huancayo measured in the same instrument was found to be 2.0 (± 0.1) times as great as it was at Kensington. The observations at Ticlio yielded a value of the total intensity 2.6 (± 0.2) times that at Kensington, and a rate of occurrence of bursts larger than 4.3×10^6 ions of 3.8 (± 0.6) per day, as compared to 3.05 (± 0.2) per day at Huancayo. It will be noted that the bursts increase with elevation more rapidly than does the total radiation (roughly as the square of the total intensity). This is in agreement with the findings of other observers [1, 2].

Discussion—Montgomery [5] has expressed the number of bursts, R, as a function of their energy, N (the energy being defined as the number of ion-pairs produced in the burst) by

$$R = AN^{-s} \tag{1}$$

where A is a constant and s is a number which is adjusted to give the best fit to the observational data. He has analyzed the results of various observers, and finds values of s ranging from 3.0 to 3.4. In the present work we find, within the limits of accuracy, an agreement with the distribution (1) for $s=3$.

The data from Table 1 are plotted in Figure 1, as observed numbers of bursts against size in ions. A straight line is passed through the points, the slope of which corresponds to $s=3$. The departures of the observed points from this line, both for the data at Kensington and at Huancayo, may be ascribed to normal fluctuations.

The curves for the distribution in energy agree with those obtained by the Montgomerys [1] at geomagnetic latitudes 40° to 50° north and at

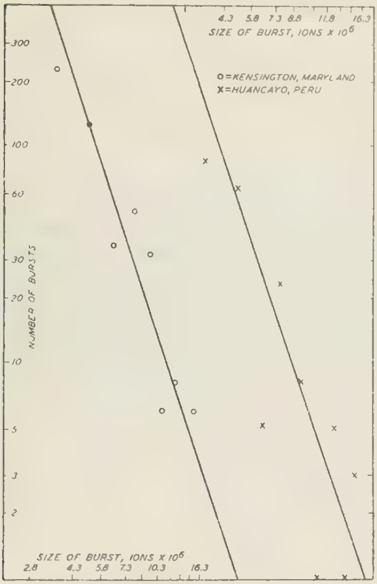

FIG. 1—OBSERVED NUMBERS OF BURSTS AT KENSINGTON, MARYLAND, AND HUANCAYO, PERU, PLOTTED AGAINST BURST-SIZE IN IONS

elevations of 4300 meters, 3500 meters, and sea-level. They agree also with those of Messerschmidt [3] at similar northern latitudes under 10 cm of lead.

The number of rays, M, involved in a burst of N ions is given by

$$M = N/(LPI) \qquad (2)$$

where L is the mean path through the chamber, P is the gas-pressure, and I is the number of ions per cm path formed by the ray at unit-pressure. For a burst of 3×10^6 ions the smallest measurable with this instrument—since L is 10 cm, P is 30 atmospheres, and I is assumed 50 ions per cm per atmosphere, we obtain 200 rays. Similarly, the largest burst recorded represents the passage of some 3000 rays through the instrument.

The ionization produced by "very large" bursts is about one part in 10^4 of the ionization produced in this instrument by "non-burst" radiation in the same period at sea-level. The contribution due to the smaller bursts is greater. The ionization produced by all bursts above the lower limit of 3×10^6 ions observable with this instrument, is one part in 10^3 of the total. At Huancayo, the total bursts produced about one part in 500 of the total ionization. Since other observers [1, 3, 5] have found the distribution expressed in (1) to apply also to smaller bursts, it appears probable that bursts, smaller than those observable with this instrument, will contribute more substantially to the total ionization.

A ratio of frequencies of occurrences of bursts between Kensington and Huancayo (3340 meters) of 4.05:1 is observed in the present work. This is in agreement, within experimental error, with a ratio of burst-frequen-

cies of 4.2:1 observed between Chicago and Echo Lake (3250 meters) by Bennett, Brown, and Rahmel [2] with a Compton-Bennett model-C meter using 12.5 cm of lead shielding. The Montgomerys [1] measured bursts at Swarthmore and Glen Cove (3500 meters) and found a ratio of frequencies of occurrences between these two stations of 14:1. However, they employed a lead shield of somewhat less than half the thickness used in the present work.

Street and Young [6] measured bursts at Cerro de Pasco, Peru (4300 meters) and at Cambridge, Massachusetts, United States. They employed a smaller instrument, and observed bursts ranging from 10 to over 40 rays each. While rough agreement is found between their work and the present, the small number of bursts (37) which they observed with a comparable (9-cm) shield makes exact comparison impossible. Consideration of the burst-frequency ratios found by the several observers cited [1, 2, 6] leads to the conclusion that the differences between them are probably due to different thicknesses of shieding used.

Conclusions—We may summarize the properties of the bursts observed:

(1) The number of bursts, R, as a function of their energy, N, in ions, may be expressed approximately by $R=AN^{-3}$ with $A=30\times 10^{12}$ ions^2 per day at sea-level.

(2) The distribution in energy of bursts does not vary, within observational error, with altitude.

(3) The distribution in energy of bursts follows, within experimental error, the same form in both the equatorial zone and in geomagnetic latitudes of 40° to 50° north.

(4) The number of bursts increases with altitude approximately as the square of the total ionization measured in the same instrument.

(5) At sea-level, very large bursts represent about one part in 10^4 of the total ionization in the instrument; total bursts above the lower limit of 3×10^6 ions, represent about one part in 10^3.

Acknowledgments—The author wishes to take this opportunity to acknowledge financial support of this project from the Carnegie Institution of Washington. He also wishes to thank Dr. J. A. Fleming and Dr. T. H. Johnson who contributed many helpful criticisms and suggestions. The work in Peru was greatly aided by Dr. G. A. Wagner, Director of the Peruvian Meteorological Service, and by the officers of the Central Railway of Peru who allowed observations to be made in the station at Ticlio.

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THE DIURNAL VARIATION OF ATMOSPHERIC CONDENSATION-NUCLEI

By N. E. Bradbury and H. J. Meuron

Abstract—Records of the diurnal variation of the density of atmospheric condensation-nuclei have been obtained over a period of four months. The apparatus employed consists of a Wilson cloud-chamber with an expansion ratio of 1.15. At regular intervals the air in the chamber is replaced by a fresh sample, saturated with water-vapor, and subjected to an expansion. A beam of light passing through the chamber is diminished in intensity by the resulting fog, and the degree of extinction may be related to the nuclei-density. The diurnal variation in nuclei-density shows a definite maximum in the forenoon and in the evening with a pronounced minimum prior to sunrise and a midday minimum of lesser extent. Such a variation might be expected in the normal daily convective cycle. The average hourly values of nuclei-density have been compared with the hourly averages of the local component of the diurnal variation of the Earth's electric field for this Station. The results indicate that in a large measure, if not entirely, the variations in the local component of the Earth's potential-gradient arise out of variations in the nuclei-density.

The study of the diurnal variation of the density of atmospheric condensation-nuclei is of interest from many points of view. Wait [see 1 of References at end of paper] has carried out such observations over short periods using an Aitken pocket dust-counter, but the requirement of visual observation imposed by this instrument makes observations over extended intervals of time exceedingly tedious. Accordingly an apparatus has been devised which operates under conditions similar to those of the Aitken counter but which yields continuous photographic record of the density of condensation-nuclei. These records, when continued over sufficiently long periods of time, become available for comparison with other atmospheric data. Of particular interest in the present investigation is the relation of the nuclei-density to the diurnal variation of the atmospheric potential-gradient. Brown [2] has suggested that a large part of the change in the local component of the potential-gradient may be due to changes in the concentration of nuclei and hence in the proportion of large ions.

Apparatus—The principle of the apparatus rests upon the extinction of a beam of light by the fog produced in a Wilson cloud-chamber. A schematic diagram of the essential parts of the apparatus is shown in Figure 1. The chamber is provided with two valve ports, V, which, when open, permit the introduction and removal of samples of air. This is accomplished by means of a small aspirator with a capacity of several liters per minute which draws in air from the outside through a two-inch tube, three feet long, lined with moist paper. The chamber contains in addition two small windows, L, diametrically opposed, through which a beam of light falls upon a Weston photronic cell, whose current actuates a galvanometer with photographic recording. To increase the effective

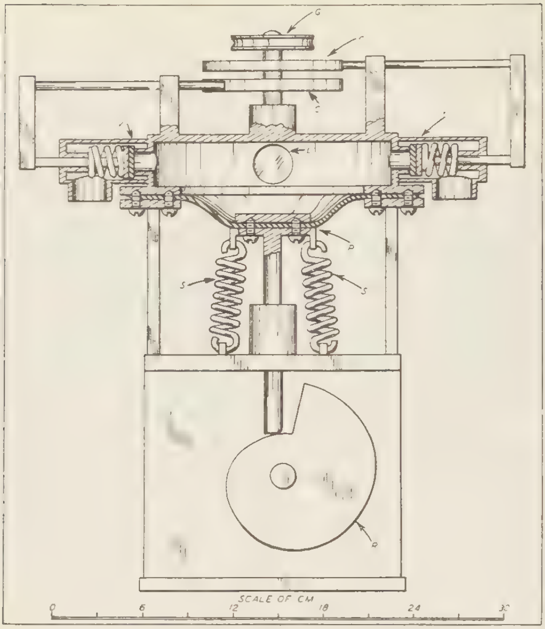

FIG 1—SCHEMATIC DIAGRAM OF THE APPARATUS

path-lengths, two mirrors are provided such that the beam of light actually passes through the chamber three times before reaching the cell. To prevent fogging a few turns of resistance-wire through which a small current could be passed are wound around the windows.

To produce an expansion, the volume of the chamber is increased by dropping the piston P. This is attached to the periphery of the chamber by means of a heavy diaphragm of rubber. Variable stops (not shown) below P permit the adjustment of the expansion-ratio to any desired value up to 1.25. The present experiments were carried out with an expansion-ratio of 1.15. The piston and diaphragm are covered with moist black velvet to minimize scattered light and to assure saturation of the air. The driving mechanism for the piston consists of the large cam R and the springs S. The shaft which drives R also is connected by a chain-drive to the gear G which rotates the cams C thus actuating the valves. These are essentially self-seating rubber discs which are kept tight by springs and the slight vacuum resulting from expansion. The whole apparatus is enclosed in a thermostated case maintained at 26°C. Constancy of the light-source is assured by employing a storage-battery and trickle-charger.

A small motor, through a reducing gear, rotates the cam R once about every fifteen minutes. The cycle of events taking place is then

as follows: Immediately following an expansion, the cams C lift the valves and air passes through the chamber flowing in from outside. This flushing continues slowly until approximately four minutes before the next expansion at which time the valves close and the air comes to equilibrium inside the chamber. Meanwhile a commutator, also attached to the shaft driving R, has closed the circuits for the light through L and the recording light of the galvanometer. The expansion then takes place, and the deflection of the galvanometer is recorded. This process is then repeated continuously.

Theory of the apparatus—C. T. R. Wilson [3] has shown that the fog produced in a cloud-chamber with small expansion-ratio arises from the presence of condensation-nuclei present in unfiltered air. If these be removed by successive expansions, no further fog is formed until the expansion-ratio is raised to a value of 1.25 or greater at which point condensation on ions begins to occur. This is the same process which occurs in the Aitken-type counter, save in this case, the number of drops is counted visually. However, if sufficient fog is present the intensity of a beam of light passing through it will be diminished, and the extent of this decrease will depend upon the number and size of the fog-droplets present. This principle is employed in the present apparatus.

The decrease in intensity of light passing through a fog-particle of cross-sectional area σ and density N/cc will be given by

$$I=I_0\exp(-N\sigma x)$$

in which I_0 is the incident intensity and I is the intensity after a distance x. If the decrease in intensity is small, the expression becomes

$$(I_0-I)/I_0=N\sigma x$$

These expressions assume that the size of the particles is large compared to the wave-length of light employed and that the droplets act as opaque discs whose diameter is that of the droplets. Both these assumptions are satisfied by the conditions of the experiment. Ideally, since I, I_0, and x are experimentally measurable quantities, if σ can be determined, the drop-density (and therefore the nuclei-density) may at once be calculated. The quantity σ may be determined approximately from Stokes' law and observations of the time required for the particles to fall a certain distance. Under the conditions of the experiment, this time can, if sufficiently large, be determined by observing the rate of return of the galvonometer-deflection. Calculations made on this assumption lead to reasonable values of the nuclei-density. However, for large droplets and hence short time of fall, the method becomes difficult, and accordingly comparison with the direct readings of an Aitken pocket counter were carried out. The results of this comparison are shown in Figure 2.

It will be seen that the nuclei-density increases faster than a direct proportion to $(I_0-I)/I_0$. In the explanation of this, the conditions under which the expansion takes place must be investigated. It has sometimes been assumed that the same amount of water condenses at an expansion, irrespective of the number of nuclei upon which drops form.

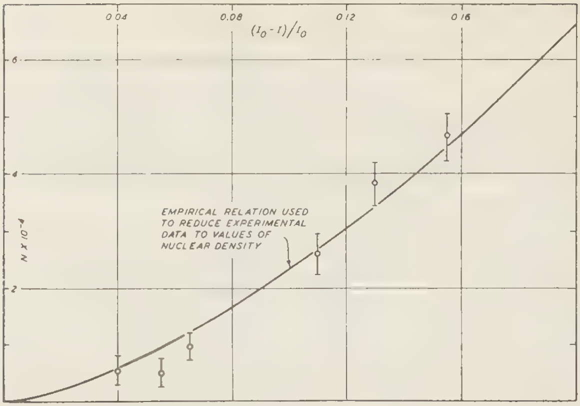

FIG. 2—PLOT OF NUCLEI-DENSITY AS DETERMINED BY MEANS OF AN AITKEN NUCLEI-COUNTER AGAINST FRACTIONAL DECREASE OF LIGHT-INTENSITY PASSING THROUGH CLOUD-CHAMBER

This is at first sight a plausible assumption inasmuch as the same amount of water is involved in supersaturation under all circumstances. Furthermore, it is a common observation that the droplets in the second and subsequent expansions of the Aitken counter are large and fall more rapidly than those of the first expansion. The same phenomenon was noticed in the operation of the present apparatus in that large deflections of the galvanometer took longer to return to I_0 than did small deflections. If this assumption be correct, then a relation exists between the size and number of droplets in such a way that the ratio $(I_0 - I)/I_0$ should be proportional to the one-third power of the nuclei-density. This was not observed to be the case, nor does it probably hold until nuclei-densities sufficiently high are reached so that the particles do not immediately fall out of the chamber. A little consideration indicates that for low nuclei-densities a limiting drop-size must be reached prior to the removal of all the excess water-vapor. This size is essentially determined by the rate at which the drop grows and its tendency to fall from the volume. For very low drop-densities, then, the nuclei-density must be directly proportional to the quantity $(I_0 - I)/I_0$. As the nuclei-density increases, this linear variation must change eventually to a relationship ending at the third power. The evidence at hand indicates that over a range between 5,000 and 50,000 nuclei per cubic centimeter a relationship of the form

$$N = K[(I_0 - I)/I_0]^{1.5}$$

holds with sufficient accuracy. The constant K has the value 7.1×10^5 in the present apparatus. In the operation of the Aitken counter, Wait [4] has observed that approximately 63 per cent of the total available nuclei fall during the first expansion. Since in the present type of ap-

paratus it is feasible to count only one expansion, it must be assumed that the first expansion always gives relatively the same fraction of total available nuclei. Some individual experiments in which successive expansions were made with the flow of air cut off indicate that the behavior of the cloud-chamber is essentially the same as that of the Aitken counter.

While it is felt that further experiments relating the results of the Aitken counter to those given by this method would be highly desirable in order to establish the absolute values of the nuclei-density, nevertheless many fruitful results may be obtained without an exact knowledge of the absolute number of nuclei per cc. Indeed, it may be impossible to define the number of nuclei in terms other than those given by some specific method. The results of Jacobs [5] indicate that the ordinary methods of determining nuclei-counts may leave undetected many nuclei whose only distinguishing characteristic may be a somewhat smaller affinity for water-vapor. Accordingly, until the exact nature and range of characteristics of atmospheric nuclei are understood, it seems unnecessary to attempt too great a refinement in methods which determine essentially only a certain class of nuclei.

Results A continuous series of daily records has been obtained for this Station between the months of January and May 1938. The location of the observing hut is in an open field well removed from strong industrial or domestic sources of condensation-nuclei. The physical aspects of the station have been described by Brown [6] and Nielsen [7]

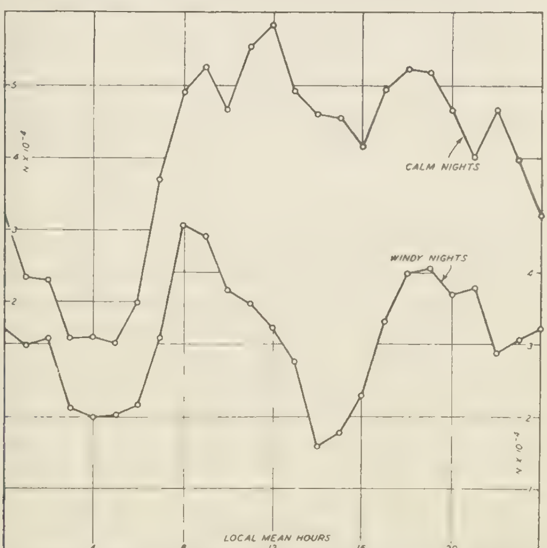

FIG. 3—NUCLEI-DENSITY FOR CALM AND WINDY NIGHTS

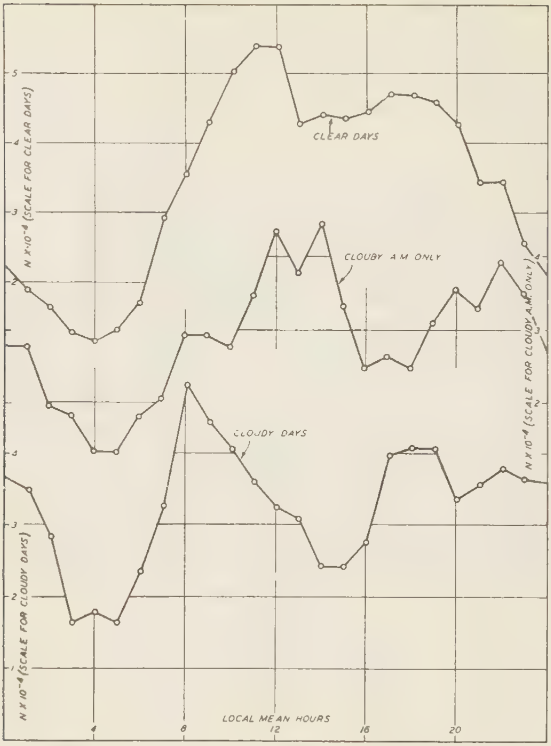

FIG. 4—NUCLEI-DENSITY FOR DAYS OF DIFFERENT CONVECTIVE CHARACTERISTICS

and remain essentially unchanged. The air-sample was taken in at a point 50 cm above the ground.

The average results are shown in Figures 3, 4, and 5. The general character of the diurnal variation is similar to that observed by Wait [1]. Essentially there appears a pronounced forenoon maximum, a midday minimum, and evening maximum followed by a steady decrease in density until sunrise. The average of all days appears in Figure 5 and will be discussed in relation to the potential-gradient. In an effort to establish the cause and mechanism of the diurnal variation, separate averages were made taking into account various meteorological conditions. In Figure 3 the effect of the night wind-velocity upon the pre-sunrise minimum has been considered. The separation between calm nights and windy nights at this Station is not as complete as might be desired owing to the almost entire absence of nights with strong winds. Accordingly the division was made on the basis of the average wind-velocity at 1 a. m. This value was 8.5 miles per hour and nights with average wind-velocities

less than five mph were considered as calm, and those with velocities greater than 11.5 mph were considered windy. Even with this limited distinction the result of night turbulence may be seen in the increased stirring and hence increased nuclei-density prior to sunrise. Furthermore, since at this Station nights with wind are generally parts of 24-hour periods with above-normal wind-velocities, the curves of Figure 3 illustrate the competition between wind-stirring and convective action. The daily range in calm days is seen to be 75 per cent greater than that for 24-hour periods with moderate wind.

The effect of the convective cycle upon the nuclei-density is also seen in Figure 4. The diurnal range is much greater on clear days when solar heating is pronounced than it is under overcast conditions. Unfortunately it was not possible to compute separately the averages for stratus-type and cumulus-type overcast conditions. The prevalence of cumulus convection is probably responsible for part of the daytime fluctuations in the cloudy-day curves. Since another frequent condition in this region is a stratus or alto-stratus overcast sky which clears about noon, days such as this were computed separately. The delay in attaining the forenoon maximum as a result of overcast conditions may be clearly seen.

It is thus suggested that the condensation-nuclei follow a daily convective cycle of the following nature: During the night in the absence of wind or turbulence, the nuclei settle out of the atmosphere probably forming a dense layer close to or on the ground. It is possible that the rate of settling is increased by condensation on the nuclei thus increasing their size. The density measured at some distance above the surface will then decrease until the rise of the Sun initiates convection. At this

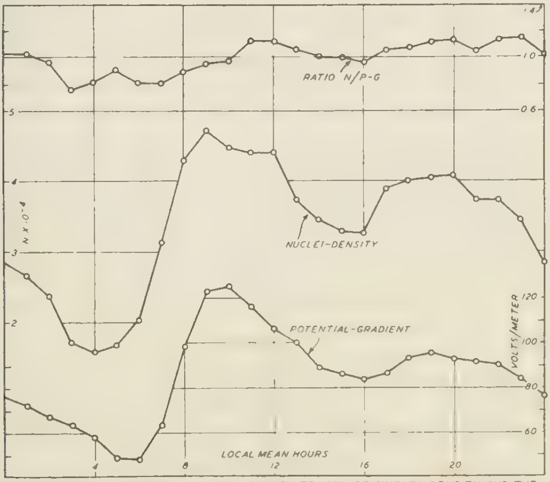

FIG. 5—THE AVERAGE OF ALL DAYS, JANUARY TO MAY, OF NUCLEI-DENSITY AND THE LOCAL COMPONENT OF THE POTENTIAL-GRADIENT AT STANFORD UNIVERSITY

time the nuclei-density begins to increase in the region from which the sample is being drawn. This process continues until extended vertical convection and mixing have diluted the nuclei to such an extent that the density near the ground decreases. Towards the end of the day, the convective process declines in intensity, the nuclei begin to settle out, and the density near the ground increases. During the night the settling process continues and the nuclei-density again falls and the cycle is completed. That such a process is not improbable is apparent from the measurements of Brown [8] on the diurnal variation of space-charge, and from the observations of Landsberg [ ] on the diurnal variation of nuclei on mountains and adjoining plains. Furthermore, it may be noted that the measurements by Wait [1] show a somewhat similar behavior.

Nuclei-density and the potential-gradient—Brown [10] has shown that, after the so-called unitary variation is removed from measurements on land of the atmospheric potential-gradient, a distinct variation still remains which is more or less similar for most land-stations and which varies with *local* time. This part of the potential-gradient he has called the local component. He has further suggested the possibility that a large portion of the variation in the local component is due to variations in the local conductivity. Since this latter will depend largely upon the concentration of small ions, any factor tending to diminish the number of small ions will decrease the conductivity and cause a corresponding increase in the gradient. It has long been suspected that condensation-nuclei were effective agents in the removal of small ions, forming from them the relatively immobile large or Langevin ion. Under these circumstances Brown has pointed out that there should exist a relationship between the local nuclei-density and the magnitude of the local component of the atmospheric potential-gradient.

In Figure 5 are plotted the average values of Brown for the local component of the atmospheric potential-gradient for the same months involved in the present study of nuclei-densities. That a definite correspondence exists can hardly be doubted even from a casual inspection. In general the nuclei-density is high when the gradient is high (that is, the conductivity is low) and the nuclei are few when the gradient is low.

In the absence of large changes in the rate of formation of ions, the density of small ions at equilibrium will be inversely proportional to the density of nuclei. If the conductivity is then proportional to the small-ion density, the gradient and the nuclei-density should be directly proportional, at equilibrium. It remains only to establish the time-interval required for a change in nuclei-density to establish equilibrium with the small-ion count. This cannot be done exactly, but if it be assumed that each collision of a nucleus and an ion results in capture with the formation of a large ion, then, depending on the size of the nuclei and the initial departure from the equilibrium state, $\sim 10^4$ seconds will be required to reach some approximation to the steady-state value. Accordingly, the values of the nuclei-density and the local component of the potential-gradient should be compared, not simultaneously but with a certain phase-interval. In the absence of exact knowledge, it was decided from inspection of the curves to compare the values of the gradient with those of the nuclei-density one hour earlier. The ratio of the gradient to the

nuclei-density is then plotted in arbitrary units in the upper curve of Figure 5. It is seen that the variation in nuclei-density is amply sufficient to account for the variation in the potential-gradient. The variations from a constant ratio may have several explanations. As has been pointed out by Wait and others, variations in the rate of formation of small ions may occur in the atmosphere with consequent changes in the conductivity. The present observations make it seem likely that changes in the conductivity due to this cause are small compared to those imposed by changes in the nuclei-content. There may, however, still be fluctuations arising from this effect. It may also be that a diurnal change in the general character of the nuclei occurs. The actual data suggest that possibly nuclei in the morning are larger, or at least more effective in producing large ions than nuclei occurring later in the day. Experimental evidence that such an effect may occur has been presented by Torreson [11] who has found that the ratio of the number of large ions to the number of nuclei is greater in the early morning that at other times of day. Wright [12], furthermore, has pointed out that such a result should follow from the change in size of a condensation-nucleus with relative humidity. While the present data are probably too limited to draw a definite conclusion in this respect, the diurnal trend of size of nuclei is in accord with these suggestions. It is therefore suggested that for this Station a close correlation exists between the nuclei-density and the local component of the atmospheric potential-gradient. This relationship may also exist for other land-stations of the type considered by Brown whose local components show midday and pre-sunrise minima.

With the limited data available at the present time it has not been feasible to consider the variation in nuclei-density with other meteorological elements. However it has been noted that short showers of even moderate intensity do not exert any striking effect upon the nuclear density. Longer periods of rainfall on the other hand appear to cause a certain washing of the atmosphere and hence a decrease in the general density of nuclei. Insufficient data are available for definite conclusions, however.

In conclusion, the authors wish to express their thanks to Professor Emeritus J. G. Brown who suggested both the experiment and its means of accomplishment. They are also greatly indebted to the Carnegie Institution of Washington for their very kind loan of an Aitken pocket nuclei-counter. Thanks are also due members of the Meteorological Staff of the United States Army Air Station at Sunnyvale, California, for their kindness in furnishing records ot the wind direction and velocity.

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FINAL RELATIVE SUNSPOT-NUMBERS FOR 1937 AND MONTHLY MEANS OF PROMINENCE-AREAS FOR 1931-1937

By W. Brunner

Table 1 contains the final sunspot-numbers for 1937, for the whole disc of the Sun, based on observations made at the Zürich Observatory, supplemented by series furnished by other cooperating observatories

TABLE 1—*Final relative sun-spot numbers for the whole disc of the Sun for 1937*

Day	Jan.	Feb.	Mar	Apr.	May	June	July	Aug.	Sep.	Oct	Nov.	Dec.
1	144	211^{a}	154^{a}	*M* 138^{c}	89	*M* 79^{c}	69^{a}	176*	108	131	104	14
2	156^{a}	224	154^{b}	128	91	89^{d}	*E* 91^{c}	180^{a}	106^{a}	*W* 170^{c}	115*	*W* 33^{c}
3	109^{a}	*E* 181^{ac}	*E* 109^{c}	112^{d}	77	92	*M* 74^{c}	*M* 207^{ac}	124^{d}	214^{abd}	105^{aa}	34*
4	*M* 107^{c}	152	*E* 65^{cd}	*E* 137^{c}	56^{ad}	116^{bd}	65^{d}	197^{d}	82	206^{b}	67	29*
5	83^{a}*	*W* 146^{ac}	76	*E* 147^{c}	59	*W* 128^{c}	91	205^{ab}	*E* 79^{c}	175*	*W* 68^{c}	54
6	*ME* 82^{cc}	128*	71	112	46	121	*E* 108^{cd}	176	*M* 85^{acd}	*E* 182^{ac}	49	56*
7	94	98	*W* 105^{c}	*M* 119^{c}	47	102	143^{add}	135	*E* 101^{c}	173^{a}*	34^{d}	67*
8	103*	*E* 90^{c}	*E* 115^{abcd}	94	*E* 50^{c}	64^{a}	*W* 185^{cd}	154^{dd}	104	157*	*E* 47^{cd}	49*
9	97	*E* 75^{c}	107	85^{ab}	68^{d}	*E* 73^{cd}	181^{bd}	173	119^{a}	*E E W* 153^{accc}	*E* 68^{c}*	56^{d}*
10	*M* 85^{cd}	85*	99	71	*M* 103^{ac}	98^{add}	192	183^{a}	119^{a}*	161^{a}	*M* 85^{c}*	*E* 56^{c}
11	97^{d}	70^{a}*	98	*E* 82^{c}	99^{a}	96	*W* 202^{ac}	140	110^{a}*	*E* 148^{acdd}	79	*E* 72^{c}
12	*W* 91^{c}	*M* 77^{acd}	59	62	91	*ME* 134^{acc}	223^{ad}	*M* 141^{c}	100^{ad}	137^{a}	83	70
13	80	87*	42^{a}	38	102*	*E* 166^{c}	188^{a}	114	110	142	100^{ab}	*M* 107^{c}
14	93	87	21	28*	*E* 123^{cd}	185	215^{aad}	124^{ab}	101	*E* 138^{c}	106	*M* 112^{acd}
15	*M* 87^{c}*	90	20	*E* 53^{acd}*	140^{ad}	191^{ad}	204^{a}	128	99	113^{d}	74	*W* 141^{ac}
16	104^{a}	101^{d}	*E* 23^{c}	64	*W* 183^{c}	*M* 174^{abcd}	180*	119	76	127^{a}	69	*E* 155^{c}
17	*E* 108^{acd}	92	22	63^{a}	188	190^{b}	152^{d}	75*	58^{d}	127^{ab}	*E* 93^{c}*	115*
18	108	88^{ad}	*E* 37^{ac}	*E* 76^{c}	158^{d}	194^{a}	167^{b}	82^{dd}	*M* 82^{ac}	121	90^{d}	109
19	101*	111^{d}	33	*E* 94^{c}	158	185	155^{a}	*E* 88^{c}	*M* 88^{c}	114^{a}	74*	124^{a}
20	*E* 128^{c}	114^{d}	*E* 42^{cd}*	*E* 127^{c}	177^{bd}	183^{a}	*E* 149^{c}	*E* 96^{c}	88^{a}	*E* 89^{cd}	82	107^{b}
21	*WE E* 127^{ccc}	130^{a}	62^{a}	127^{a}	154^{aad}	186^{d}	150	80	*M* 73^{c}	72^{a}	62	86
22	163	190^{add}	*M* 74^{c}	*M* 146^{bb}*	*E* 194^{ac}	199^{ad}	145^{d}	*W* 103^{c}	102*	58	62*	*E* 90^{cd}
23	155	155^{a}	*E* 107^{cd}	144^{b}	202	*M* 163^{ac}	139^{a}	*E M* 139^{aacc}	*E* 128^{cd}*	*W* 63^{c}	59^{a}	*E* 107^{c}
24	178^{abdd}	187^{ad}	94^{d}*	*M* 157^{bc}	213^{a}	133	126	150	120^{a}	*E* 75^{cd}	50*	116*
25	*M* 181^{ac}	162^{aa}	87	*ME* 190^{acc}	171	108	124	137^{ab}	*E M* 127^{cc}	69	*M* 61^{c}*	*E* 124^{acd}*
26	*E* 200^{bcd}	*E* 167^{ac}	80^{a}	157	130^{a}	116	115^{d}	*E* 144^{c}	104	59^{b}	*M* 70^{c}	114*
27	*E* 180^{c}	149	118^{a}	161	93^{b}	91^{b}	148^{d}	143^{d}	80	58	96	125^{aa}
28	201	*W* 150^{ac}*	131	149	71	80^{a}	124^{b}	130	101^{ad}	*E* 104^{c}	64	103^{a}
29	*M* 200^{cd}*		117^{a}	123^{bd}	*E* 83^{cd}	*E* 80^{c}	*E* 128^{bc}	110	126^{aa}	90^{ad}	68	*M M* 111^{cc}
30	233^{ab}		*E* 135^{ac}	94^{b}	103	93	*E* 139^{cd}	109^{d}	*E* 121^{cd}	*E* 113^{c}	47	*M* 110^{c}
31	233^{ab}		143^{a}		98		*E* 131^{c}	128		133^{a}		112^{ad}
Mean	132.5	128.5	83.9	109.3	116 7	130 3	145 1	137 7	100 7	124.9	74.4	88 8

^{a} = Passage of an average-sized group through the central meridian.
^{b} = Passage of a large group or spot through the central meridian.
^{c} = New formation of a group developing into a middle-sized or large center of activity: *E*, on the eastern part of the Sun's disc; *W*, on the western part; *M*, in the central-circle zone.
^{d} = Entrance of a large or average-sized center of activity on the east limb.

for days (indicated by asterisks) on which no observations were possible at Zürich.

Table 2 gives the yearly means of the relative numbers, R, since the last minimum 1933 and the number of days without spots.

TABLE 2—*Yearly means of relative sunspot-numbers, R*

Year	R	Increase	No. spotless days
1933	5.7		240
1934	8.7	3.0	154
1935	36.1	27.4	20
1936	79.7	43.6	0
1937	114.4	34.7	0

Figure 1 gives a graphical representation of the daily relative sunspot-numbers for 1937, the times being plotted as abscissas and the relative numbers as ordinates. The limits of the successive solar rotations are indicated by vertical arrows in the upper edge of the Figure. The

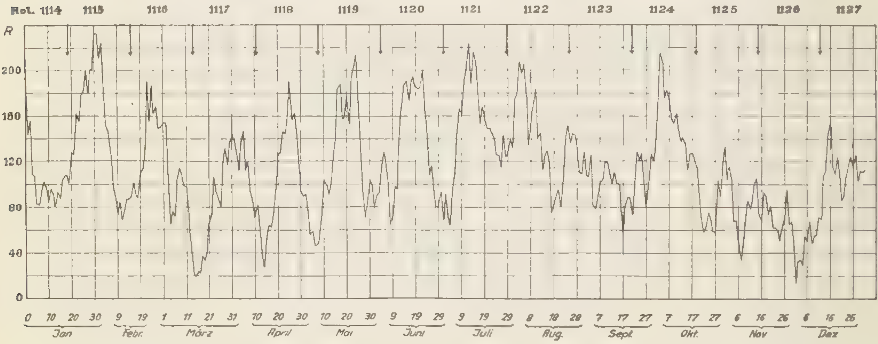


FIG. 1—DAILY RELATIVE SUNSPOT-NUMBERS FOR 1937

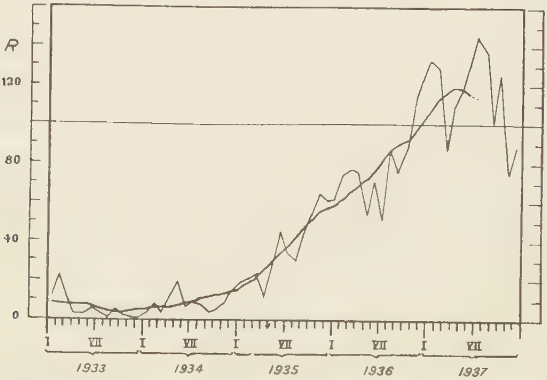


FIG. 2—OBSERVED AND SMOOTHED MONTHLY RELATIVE NUMBERS FOR 1933 TO 1937

secondary maxima and minima succeeding the rotation-periods do not represent real fluctuations in sunspot-activity, but are rather to be attributed to the influence of solar rotation, to a certain stability of the centers of activity for spots, and to the special distribution of these centers of activity in the direction of rotation.

Figure 2 shows the observed and smoothed monthly relative numbers for 1933 to 1937. The purpose of smoothing is to eliminate the secondary variations. The method of smoothing is as follows: For obtaining the mean of the epoch July 1, the average of the monthly means of the twelve months January to December is taken (m_1), and for the epoch August 1, the average of the monthly means for February to January (m_2). The mean of these $m = (m_1 + m_2)/2$, which represents the smoothed

TABLE 3—*Monthly means of prominence-areas for 1931-1937*[1]

	1931[2]	1932	1933	1934	1935	1936	1937
Jan.	193$_{9}$	518$_{23}$	404$_{17}$	480$_{15}$	751$_{14}$	1005$_{6}$	1672$_{10}$
Feb.	279$_{9}$	513$_{30}$	426$_{15}$	427$_{35}$	573$_{11}$	987$_{15}$	1699$_{5}$
Mar.	197$_{20}$	511$_{23}$	396$_{34}$	387$_{20}$	715$_{27}$	868$_{23}$	1027$_{11}$
Apr.	255$_{15}$	445$_{18}$	323$_{18}$	431$_{31}$	897$_{7}$	1071$_{5}$	1174$_{16}$
May	362$_{21}$	338$_{17}$	329$_{16}$	539$_{34}$	896$_{19}$	1284$_{19}$	1329$_{25}$
June	294$_{25}$	443$_{23}$	565$_{18}$	592$_{36}$	738$_{26}$	905$_{18}$	1312$_{18}$
July	468$_{25}$	437$_{23}$	568$_{39}$	616$_{32}$	885$_{25}$	790$_{20}$	1010$_{15}$
Aug.	656$_{22}$	376$_{34}$	460$_{32}$	493$_{19}$	1206$_{22}$	965$_{35}$	896$_{13}$
Sep.	552$_{22}$	440$_{21}$	597$_{17}$	763$_{30}$	1399$_{26}$	1094$_{17}$	1312$_{18}$
Oct.	655$_{32}$	302$_{18}$	582$_{23}$	625$_{27}$	1058$_{8}$	1314$_{21}$	1169$_{16}$
Nov.	480$_{19}$	363$_{27}$	319$_{12}$	542$_{19}$	1155$_{14}$	1505$_{15}$	842$_{18}$
Dec.	494$_{25}$	439$_{17}$	376$_{24}$	438$_{17}$	1505$_{9}$	1531$_{14}$	1004$_{7}$
Yearly Mean	407$_{245}$	427$_{274}$	445$_{265}$	528$_{305}$	981$_{208}$	1110$_{208}$	1204$_{172}$

[1]For corresponding returns for the years 1909-30, see Terr. Mag., **42**. 393, 1937.
[2]Zürich and Arosa from August 1931.

relative number for the middle of July, is used for the construction of the curve.

To this summary of spot-activity for the past year I am adding Table 3 showing the activity of the prominences by monthly means of the measured areas for the period 1931 to 1937.

EIDGEN, STERNWARTE,
Zürich, Switzerland

NOTES

(See also pages 226 and 342)

29. *Notes on magnetic work, United States Coast and Geodetic Survey*—Magnetic repeat-observations were made in California and Montana by F. P. Ulrich and in Missouri, Arkansas, Tennessee, Kentucky, Ohio, Michigan, Wisconsin, North Dakota, and Minnesota by S. A. Deel.

The Survey has been granted an allotment from Public Works Funds for the repairs of instruments, equipment, and buildings of the Cheltenham and Tucson magnetic observatories.

Three QHM's, recently received, will be compared at Cheltenham, and thereafter used for making interobservatory comparisons.

Work has begun to redetermine constants and the standardizations of magnetometers 31 and 37, recently rebuilt in the instrument-shops at the Survey.

Publications recently issued by the Survey include Serial 601, "Magnetic declination in Arkansas, 1935," and Serial 602, "United States magnetic tables and magnetic charts for 1935."

30. *MacGregor Arctic Expedition*—The MacGregor Arctic Expedition which has been at winter base at Reindeer Point, Greenland, sailed from Etah, Greenland, July 7, 1938, on the return voyage to the United States, having successfully completed the extensive program of magnetic, meteorological, auroral, and exploratory work.

31. *Transfer of the Tashkent Magnetic Observatory*—Because of the extension of electric-tram lines at Tashkent, U.S.S.R., the magnetic section of the Tashkent Geophysical Observatory has been transferred to a point about 1.5 km from the railway station at Keles, about 12 km from Tashkent. The station consists of an underground chamber for magnetographs and a building for absolute observations. The floor of the underground room is three meters below the surface and is two meters high, three meters long, and 1.5 meters wide. The new station is in latitude 41° 25′ north and longitude 69° 14′ east. All the instruments were transferred from Tashkent to Keles in December 1935. Systematic registration was begun in August 1936.

32. *Observatory of Zo-sè*—It will be of interest to the readers of the JOURNAL to know that the magnetic work at the Zo-sè Observatory on July 1, 1938, was going forward as usual despite the unsettled conditions in China.

33. *Italian National Research Council*—The *Bollettino del Comitato per la Geodesia e la Geofisica del Consiglio Nazionale delle Ricerche* for October 1937 states that the Italian National Research Council has formed new National Committees including (1) Astronomy and Geodesy and (2) Geophysics and Meteoroogy. The *Bulletin*, however, will continue with the same program and form but the third series, which begins with January 1938, will bear the slightly modified title *Bollettino de Geodesia e di Geofisica del Consiglio Nazionale delle Ricerche.*

34. *Corrigenda*—In the isuue of June 1938 corrections should be made as follows: Page 121, fourteenth line, read "directions" for "for "direction"; page 122, seventh line from bottom, read "unicrystals" for "multicrystals," and in sixth line from bottom, read "multicrystalline" for "unicrystalline"; page 133, second line from bottom, read "gewählte" for "letzte"; page 134, second line of Table 3, read "Potsdam" for "Postdam," and first line of last paragraph, read "unveröffentlichten" for "unveroffentlichen"; page 158, third line of reference 7, read "Veroff." for "Beroff."

MAGNETIC CHARACTER OF THE YEARS 1890-1905*

By G. van Dijk

Twenty-nine observatories have contributed to the establishment of the magnetic character of the years 1890-1905. In preparing the annual summaries, the numbers missing from the original lists have been interpolated with the greatest possible care. In general, when the numbers for three months or more were lacking for a given station, the data for that station for that year have not been used in computing the daily, monthly, and annual means.

The numbers of stations used in preparing the annual summaries for the years 1890-1905 were successively: 11; 13; 14; 14; 14; 13; 16; 16; 15;

Table 1—*Monthly and annual mean magnetic character-figures, 1890-1905*

Month	Year							
	1890	1891	1892	1893	1894	1895	1896	1897
January	0.61	0.54	0.76	0.76	0.75	0.72	0.97	0.59
February	0.59	0.71	0.95	0.76	1.01	0.93	0.94	0.68
March	0.52	0.85	1.03	0.73	0.77	0.95	0.84	0.70
April	0.53	0.85	0.70	0.69	0.78	0.83	0.71	0.87
May	0.49	0.83	0.85	0.63	0.76	0.72	0.70	0.73
June	0.48	0.56	0.69	0.76	0.80	0.66	0.51	0.62
July	0.53	0.55	0.91	0.67	0.86	0.75	0.57	0.49
August	0.53	0.68	0.73	0.72	0.72	0.51	0.72	0.58
September	0.69	0.83	0.78	0.81	0.81	0.61	0.70	0.62
October	0.76	0.76	0.90	0.83	0.73	0.93	0.65	0.68
November	0.64	0.59	0.71	0.75	0.80	0.87	0.58	0.67
December	0.49	0.63	0.80	0.61	0.59	0.65	0.60	0.77
Annual	0.571	0.698	0.818	0.724	0.779	0.758	0.703	0.666

Month	Year							
	1898	1899	1900	1901	1902	1903	1904	1905
January	0.68	0.69	0.63	0.44	0.36	0.43	0.69	0.68
February	0.68	0.74	0.49	0.42	0.51	0.35	0.55	0.74
March	0.80	0.74	0.58	0.48	0.39	0.45	0.42	0.63
April	0.65	0.71	0.44	0.43	0.48	0.57	0.62	0.55
May	0.67	0.71	0.45	0.46	0.43	0.52	0.61	0.47
June	0.64	0.57	0.29	0.51	0.45	0.62	0.50	0.57
July	0.64	0.56	0.31	0.48	0.45	0.57	0.57	0.48
August	0.70	0.60	0.37	0.47	0.43	0.67	0.46	0.69
September	0.78	0.66	0.40	0.43	0.45	0.73	0.53	0.67
October	0.68	0.49	0.38	0.41	0.49	0.80	0.58	0.47
November	0.65	0.48	0.33	0.38	0.46	0.75	0.54	0.68
December	0.65	0.63	0.32	0.44	0.43	0.62	0.50	0.42
Annual	0.686	0.630	0.415	0.446	0.443	0.592	0.548	0.586

*Prepared under the auspices of the Association of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics.

17; 18; 17; 22; 24; 26; and 26. They result from data supplied for the following observatories:

1890-1905—Potsdam, Greenwich, Parc St. Maur-Val Joyeux, Zi-ka-wei, Bombay, Mauritius, and Melbourne
1890-1897 and 1899-1905—Toronto-Agincourt
1890-1900 and 1902-1905—Batavia-Buitenzorg
1890-1894—San Antonio (Texas)
1890-1904—Manila
1891-1905—Utrecht-DeBilt and San Fernando
1892-1900—Copenhagen
1896-1905—Pavlovsk, Bochum, and Pola
1899-1905—Munich
1900-1905—Tiflis
1901-1905—Baldwin
1902-1905—Sitka, Cheltenham, Dehra Dun, and Honolulu
1903-1905—Vieques and Kodaikanal
1904-1905—Ekaterinburg and Barrackpore
1905—Toungoo

The monthly and annual means are given in Table 1.

ROYAL METEOROLOGICAL INSTITUTE OF THE NETHERLANDS,
De Bilt, May, 1938

INTERNATIONAL SELECTED MAGNETICALLY QUIET DAYS AND DISTURBED DAYS, 1890-1894*

By G. van Dijk

Table 1—*Selected quiet days, 1890-1894*

Month	Year														
	1890					1891					1892				
January	2	8	9	27	31	4	7	8	26	31	2	9	14	25	27
February	7	10	23	25	28	3	4	20	21	28	10	11	17	22	23
March	2	27	28	29	30	1	10	11	28	29	17	19	20	22	23
April	3	4	10	18	26	6	19	26	27	30	16	17	19	20	21
May	2	27	28	29	30	1	2	23	24	25	12	13	15	23	26
June	8	14	16	26	27	10	12	13	28	29	11	12	13	14	15
July	2	14	16	27	28	9	12	19	22	31	5	6	7	20	23
August	3	11	12	13	30	6	7	23	24	25	2	14	15	19	28
September	1	8	9	23	27	6	7	18	20	25	5	9	18	19	25
October	2	4	7	23	29	6	15	16	17	22	9	25	26	28	29
November	3	5	6	28	29	2	6	7	9	30	8	11	12	13	20
December	4	16	18	19	27	1	17	18	24	27	2	3	9	10	20

Month	1893					1894				
January	15	16	17	25	27	8	15	16	17	20
February	1	13	23	24	26	1	8	10	11	13
March	18	19	20	21	22	5	7	13	27	28
April	4	9	21	22	23	3	4	9	11	23
May	1	2	22	28	29	10	11	12	25	26
June	8	13	17	23	24	5	6	7	24	26
July	5	6	9	30	31	7	10	11	14	26
August	1	17	24	27	28	1	2	17	18	31
September	4	7	22	23	24	3	4	6	13	26
October	19	20	21	22	23	10	11	12	15	23
November	11	15	16	20	21	4	5	6	21	22
December	7	17	18	21	22	3	4	11	25	26

The selected quiet days for 1895-1905 are given in Terr. Mag., **42**, 397 (1937).

The selected quiet days for 1906 and following years will be found in the publication "Caractère magnétique de chaque jour." An annual summary also appears regularly in each volume of this Journal.

*Prepared under the auspices of the Association of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics.

TABLE 2—*Selected disturbed days, 1890-1904*

Month	Year														
	1890					1891					1892				
January	3	11	18	20	21	16	17	18	19	24	4	5	6	17	29
February	3	15	18	19	20	11	12	13	14	15	13	14	20	21	27
March	11	12	16	17	18	2	3	5	24	31	1	6	7	11	12
April	1	7	22	23	30	7	8	9	12	17	9	24	25	26	27
May	4	5	6	17	25	4	13	14	15	16	1	2	8	18	19
June	2	4	5	21	22	5	14	15	20	27	2	3	16	27	28
July	6	17	18	19	20	4	6	7	17	24	12	14	16	17	26
August	14	15	16	17	18	2	3	19	29	30	3	4	12	25	26
September	11	12	15	16	20	9	10	11	12	28	11	13	16	21	22
October	6	10	15	18	19	8	23	24	25	26	12	15	16	18	19
November	8	9	13	14	15	15	16	17	20	21	4	5	17	18	24
December	5	21	22	23	28	7	8	9	22	30	4	5	13	23	24
	1893					1894									
January	5	9	21	22	29	3	4	11	12	13					
February	4	5	14	16	17	21	23	24	25	28					
March	14	15	25	26	28	1	21	22	30	31					
April	12	13	26	27	28	6	13	17	18	19					
May	7	8	9	18	30	1	14	15	28	31					
June	9	18	19	28	29	9	10	11	17	21					
July	14	15	16	21	22	2	18	19	20	21					
August	6	7	12	13	18	13	14	15	20	21					
September	5	8	9	26	30	14	15	19	20	21					
October	2	10	25	26	29	5	16	17	25	31					
November	1	2	3	27	28	13	14	17	18	23					
December	5	6	24	25	30	5	13	15	21	22					

For selected disturbed days for 1895-1905 see Terr. Mag., **42**, 398 (1937), and for 1906-1914 see Trans. Edinbugh Meeting, 1936, Ass. Terr. Mag. Electr., Internat. Union Geod. Geophys., Bull. 10, p. 440 (1937).

The selected disturbed days for 1917 and following years will be found in the publication "Caractère magnétique de chaque jour." An annual summary also appears regularly in each volume of this JOURNAL.

ROYAL METEOROLOGICAL INSTITUTE OF THE NETHERLANDS,
De Bilt, May, 1938

SCATTERING OF RADIO WAVES BY THE *F*-REGION OF THE IONOSPHERE

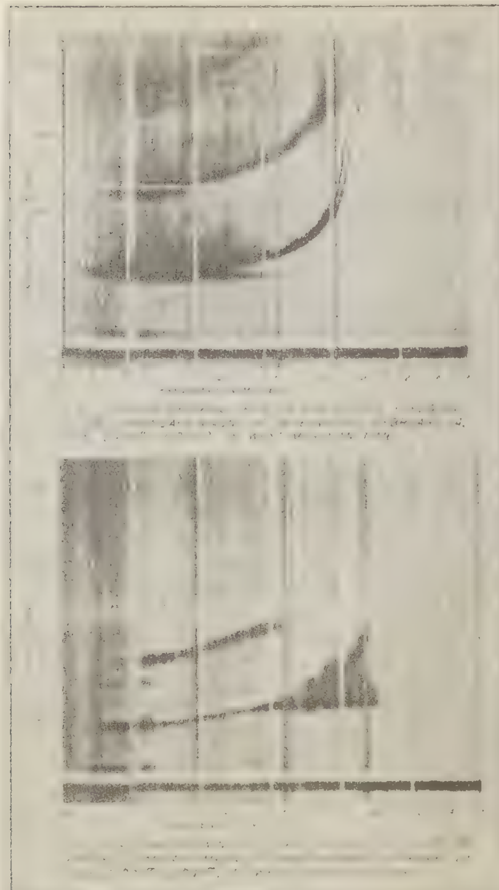
By H. G. Booker and H. W. Wells

Abstract—Records are reproduced showing diffuse echoes from the *F*-region of the ionosphere received continuously at night in equatorial regions over a wide range of wave-frequency. They are interpreted as due to Rayleigh scattering by spatial irregularities in the distribution of electron-density at or above a definite level in the *F*-region. Because of the highly dispersive nature of the ionosphere, there is no marked dependence of Rayleigh scattering upon wave-frequency such as there is for a non-dispersive medium. According to this interpretation, variation of the maximum wave-frequency to which diffuse echoes can be followed has nothing to do with variation of the maximum electron-density of an ionospheric region, but merely indicates variation in the size of irregularities in electron-density. Scattering of this type may have some bearing upon the phenomenon of persistence of *E*-region echoes to wave-frequencies greater than the critical penetration-frequency of the *E*-region.

Transient radio echoes from the *E*-region of the ionosphere attributable to temporary existence of marked scattering centers have been observed by Appleton, Naismith, and Ingram [see 1 under References at end of paper], by Eckersley [2], and by Appleton and Piddington [3]. Lateral deviation of radio waves attributable to scattering of a more persistent nature has been observed by Ratcliffe and Pawsey [4], by Pawsey [5], and by Martyn and Green [6]. The purpose of this note is to describe echoes which seem attributable to scattering from the *F*-region of the ionosphere. They have been received continuously at night in equatorial regions over a wide range of wave-frequency.

Figures 1, 2, and 3 show ionospheric records obtained at the Observatory maintained near Huancayo, Peru, by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. They were made by the automatic multifrequency technique of vertical radio sounding of the ionosphere [7]. The records show the way in which the virtual heights of ionospheric echoes vary with wave-frequency. Each record takes 15 minutes to make, during which time the wave-frequency changes continuously from 16.0 to 0.5 mc sec. The four records of Figure 3 were made at intervals of 45 minutes, beginning before sunrise and continuing through the sunrise-period. Figure 3-*D* shows what may be regarded as a normal record. On it may be seen echoes from the *E*-region of the ionosphere at a height of about 100 km, and from the *F*-region at heights above 200 km. Multiple echoes due to reflection back and forth between the *F*-region and the Earth's surface may also be seen. Figure 3-*A* on the other hand shows a record of a very different character. On all wave-frequencies between about one and ten mc sec echoes are obtained with virtual heights ranging upward from a minimum at about 420 km. Over this wide frequency-range there is little change in the character of the echoes. Their amplitudes decrease with increase of virtual height from a maximum at the lowest virtual height from which they are received. The amplitudes of the echoes are practically independent of wave-frequency up to a wave-frequency of about ten mc sec. With further increase of wave-frequency, however, the echoes become weaker, and they disappear altogether at a wave-frequency between 11 and 12 mc sec.

The phenomenon indicated in Figure 3-*A* has occurred at Huancayo to a greater or less extent almost every night during the winter of 1937-38



There is no obvious correlation with magnetic activity. The phenomenon sets in between about $19^{h}\,00^{m}$ and $20^{h}\,00^{m}$, local time, in the manner indicated by the record reproduced in Figure 1. The onset of the phenomenon is closely correlated with a marked rise of 100 km or more in the height of the *F*-region between about $18^{h}\,00^{m}$ and $20^{h}\,00^{m}$, local time. The disappearance of the phenomenon seems to be correlated with subsequent decrease of the height of the *F*-region later in the night. On some occasions the *F*-region remains at a great height throughout the night. During the sunrise-period there is then a rapid fall in the height of the region, combined with a rapid increase in maximum electron-density. On these occasions the phenomenon indicated in Figure 3-*A* disappears in the manner indicated in Figure 3-*B*, 3-*C*, and 3-*D*. It will be noticed that in Figure 3-*B* and 3-*C* there is a frequency-range over which we obtain both the regular *F*-region echoes of Figure 3-*D* and the

diffuse echoes of Figure 3-*A*. In this frequency-range the minimum virtual height of the diffuse echoes increases to infinity with decrease of wave-frequency. On the other hand the virtual heights of the regular *F*-region echoes increase to infinity with increase of wave-frequency in the usual way.

The maximum wave-frequency at which regular *F*-region echoes are obtained is the critical penetration-frequency of the *F*-region, and is a measure of the maximum electron-density in the region. For the record reproduced in Figure 3-*B*, the regular *F*-region echoes show that the maximum electron-density in the *F*-region was of the order of 10^5 cc. We may take it that, for the record reproduced in Figure 3-*A*, the maximum electron-density in the *F*-region was also about 10^5 cc. This is more than an order of magnitude less than that which would be required to give regular reflection up to a wave-frequency between 11 and 12 mc/sec, which is the wave-frequency up to which diffuse echoes can be seen in Figure 3-*A*. We shall therefore make no attempt to associate the diffuse echoes with any form of regular reflection, or to connect the maximum wave-frequency to which they can be followed with the maximum electron-density of an ionospheric region. On the contrary, we

shall interpret the diffuse echoes as due to scattering by spatial irregularities in the distribution of electron-density in the F-region. Estimates of scattering produced by simple irregularities seem to indicate that enormous irregularities are not required in order to explain the diffuse echoes. We shall assume therefore that these echoes are due to existence in the F-region of electronic clouds, the maximum electron-density in which is not more that two or three times the average maximum electron-density in the F-region.

Consider a cloud of electrons in the ionosphere. Suppose that its linear dimensions are small compared with the wave-length of the radio wave. Let μ be the refractive index of the cloud, and μ_0 that of its surroundings. Suppose that there is incident upon the cloud a radio wave of frequency f and intensity I (proportional to square of amplitude). Then, if i is the intensity of the scattered wave, we have according to Rayleigh

$$i/I \propto f^4(\mu^2-\mu^2{}_0)^2 \tag{1}$$

As is well known, (1) shows that, for a non-dispersive medium, the intensity of the scattered wave increases markedly with increase of wave-frequency, being proportional to f^4. For the ionosphere, however, there is no such marked dependence of scattering upon wave-frequency. The reason for this is that the ionosphere is a highly dispersive medium. A given change in electron-density causes a larger change in refractive index at low wave-frequencies than at high. This produces a dependence of scattering upon wave-frequency which counterbalances that existing for a non-dispersive medium. We may put this explicitly as follows. Let e and m be the charge and mass of an electron. Let N be the electron-density in the cloud and N_0 that in its surroundings. The simplest relation we can assume between μ, N, and f is

$$\mu^2 = 1 - \frac{N}{(\pi m/e^2)f^2} \tag{2}$$

If we subtract from (2) the equation

$$\mu^2{}_0 = 1 - \frac{N_0}{(\pi m/e^2)f^2} \tag{3}$$

we obtain

$$\mu^2 - \mu^2{}_0 = \frac{N_0 - N}{(\pi m/e^2)f^2} \tag{4}$$

Substitution of (4) into (1) gives

$$i/I \propto f^4 \frac{(N_0-N)^2}{(\pi m/e^2)^2 f^4} \tag{5}$$

We see that the f^4-factors cancel out, and we are left with

$$i/I \propto (e^2/\pi m)^2 \, (N - N_0)^2 \tag{6}$$

The right-hand side of (6) depends upon the difference between the electron-density in the cloud and that in its surroundings, but is independent of wave-frequency. For the actual ionosphere there will, as a matter of fact, be some dependence of scattering upon wave-frequency.

This is partly because the dependence of intensity of scattered wave upon refractive index is a little more complicated than is indicated by (1), and partly because the dependence of refractive index upon wave-frequency is a little more complicated than is indicated by (2). But the salient fact remains that, for Rayleigh scattering of radio waves by the ionosphere, there should be no marked dependence upon wave-frequency.

We have already mentioned that, for the record reproduced in Figure 3-*A*, there is no marked dependence of the character of the echoes upon wave-frequency over the wide frequency-range from one to ten mc/sec. This would agree with the hypothesis that these echoes are due to Rayleigh scattering by spatial irregularities in the distribution of electron-density in the *F*-region. The question arises however as to why at higher frequencies the echoes become weaker, and disappear altogether at a wave-frequency between 11 and 12 mc/sec.

The theory of Rayleigh scattering assumes that the linear dimensions of scattering centers are small compared with the wave-length of incident radiation. The theory of Rayleigh scattering by the ionosphere therefore assumes that the linear dimensions of irregularities in electron-density are small compared with the wave-length of incident radio waves. As the wave-frequency increases, however, the wave-length decreases. With sufficient increase of wave-frequency, the wave-length must become comparable with the linear dimensions of irregularities in electron-density. We therefore interpret the wave-length corresponding to the maximum wave-frequency to which scattered echoes can be followed as indicating the linear dimensions of the irregularities in electron-density. For the record reproduced in Figure 3-*A*, the maximum wave-frequency to which the scattered echoes can be followed is between 11 and 12 mc/sec. The corresponding wave-length is about 25 meters. We therefore interpret Figure 3-*A* as indicating existence in the *F*-region of irregularities in electron-density, the linear dimensions of which are of the order of 25 meters. For radio waves of wave-length appreciably longer that 25 meters, these irregularities produce Rayleigh scattering. This, on account of the dispersive nature of the medium, is practically independent of the extent by which the wave-length exceeds 25 meters. On the other hand, for radio waves of wave-length appreciably shorter than 25 meters, the linear dimensions of the irregularities are appreciably larger than the wave-length. Consequently any scattering they produce is accomplished by ordinary refraction. No appreciable scattering of this type occurs for the record reproduced in Figure 3-*A* because, when the wave-length is appreciably less than 25 meters, the wave-frequency is at least an order of magnitude greater than the critical penetration-frequency even of the electronic clouds.

If the above interpretation of the diffuse echoes of Figure 3-*A* is correct, it is important to notice that variation of the maximum wave-frequency to which these echoes can be followed has nothing whatever to do with variation of the maximum electron-density of an ionospheric region. It merely indicates variation in the size of the scattering centers. It seems possible that scattering of the type here postulated may also have some bearing upon the phenomenon of persistence of *E*-region echoes to wave-frequencies greater than the critical penetration-frequency of the *E*-region.

The records seem to indicate that irregularities in electron-density

do not in general exist throughout the entire *F*-region, but only at or above a definite level in the *F*-region. For the record reproduced in Figures 1, 2, and 3, this level is about 420 km. We interpret echoes of minimum virtual height in Figure 3-*A* as ones which, after having travelled vertically up to a height of about 420 km, have been scattered backwards, and have then travelled vertically back to the equipment. Echoes of greater virtual height we interpret as ones which have travelled up to, and back again from, the same scattering-level at a height of about 420 km, but at some angle to the vertical. For example, an echo of virtual height three-halves the minimum virtual height is one which has travelled at an angle $\cos^{-1}(2/3)$ to the vertical.

We have now to explain why, for the records reproduced in Figure 3-*B* and 3-*C*, there is a frequency-range over which we obtain not only the regular *F*-region echoes but also the scattered echoes, and why the minimum virtual height of the scattered echoes increases continuously to infinity with decrease of wave-frequency. In Figure 4 is shown what we may regard as an east-west cross-section of the *F*-region of the iono-

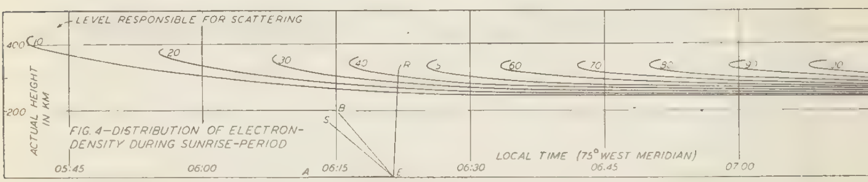


FIG. 4—DISTRIBUTION OF ELECTRON-DENSITY DURING SUNRISE-PERIOD

sphere by a vertical plane through Huancayo during the sunrise-period on February 10, 1938. The curves represent surfaces of equal electron-density. The numbers attached to the curves are proportional to electron-density. This Figure was deduced in the following way: From the records reproduced in Figure 3, together with intervening records not reproduced, we deduced by interpolation the variation of virtual height with wave-frequency which would have been obtained for the regular *F*-region echoes every 15 minutes if simultaneous observations had been made over the entire frequency-range. To the series of curves thus obtained we fitted, by a method of least squares, parabolic maxima of electron-density, neglecting the possible effect of the Lorentz polarization-correction. We then represented the variation with time of the distribution of electron-density with height by means of the contours shown in Figure 4. The curves are incomplete because the records give information about the distribution of electron-density only below the level of maximum electron-density. The scales in Figure 4 have been so chosen that 15 minutes on the horizontal scale is equivalent to 400 km on the vertical scale. Now, at the equator, sunrise advances westwards about 400 km every 15 minutes. Consequently, if we neglect curvature of the Earth's surface, we may regard Figure 4 as giving an approximate east-west cross-section of the ionosphere through Huancayo. The equipment may be regarded as moving from left to right along the horizontal axis at the rate of 400 km every 15 minutes, its position relative to the distribution of electron-density at any time being as indicated. It will be seen that, during the sunrise-period, the surfaces of equal electron-density above Huancayo are by no means horizontal. This is why, for

the records reproduced in Figure 3-*B* and 3-*C*, there is a frequency-range over which we obtain both regular *F*-region echoes and scattered echoes. The level responsible for scattering is indicated in Figure 4 by shading. The point *E* indicates the position of the equipment relative to the distribution of electron-density at the moment when the wave-frequency 6.5 mc sec was being radiated for the record reproduced in Figure 3-*C*. *ER* indicates the path of the regular *F*-region echo. *AEB* indicates the angle within which the scattered echoes are being received. Scattered echoes received in the direction *AE* would obviously have an infinite virtual height. Scattered echoes received in the direction *BE* would also have an infinite virtual height because they are only just penetrating the ionization which exists below the level responsible for scattering. Consequently there is a direction *SE* which gives the minimum virtual height of the scattered echoes at this wave-frequency. With decrease of wave-frequency the angle *AES* decreases. Consequently the minimum virtual height of the scattered echoes increases as shown in the record reproduced in Figure 3-*C*. It may be mentioned that at the top of this record there may be seen echoes which seem to be due to scattering subsequent to regular reflection back and forth between the *F*-region and the Earth's surface.

The increase to infinity of the minimum virtual height of the scattered echoes of Figure 3-*C* with decrease of wave-frequency is an indication that the level responsible for scattering was above the level of maximum electron-desity in the *F*-region as shown in Figure 4. For the records reproduced in Figures 1 and 2, however, there is no increase to infinity of the minimum virtual height of the scattered echoes with decrease of wave-frequency. (Such increase as exists in Figure 1 at wave-frequencies less that 1.5 mc/sec is due, of course, to the effect of ionization in the *E*-region.) We interpret this as indicating that the level responsible for scattering was below the level of maximum electron-density in the *F*-region.

The situation above Huancayo during most evenings of the winter of 1937-38 would seem therefore to have been as follows. Between about $18^h\,00^m$ and $19^h\,00^m$, local time, there are irregularities in electron-density at or above a certain level which is higher than the level of maximum electron-density in the *F*-region. But the size of the irregularities in electron-density is too large to allow appreciable scattering to take place at wave-frequencies greater than the critical penetration-frequency of the *F*-region. Between about $18^h\,00^m$ and $20^h\,00^m$, local time, the height of the *F*-region increases by 100 km or more. During this period the level of maximum electron-density ascends to a height considerably greater than that at or above which irregularities in electron-density exist, and a level where scattering takes place is revealed as indicated by the record reproduced in Figure 1. If the size of the irregularities in electron-density decreases and the height of the *F*-region also decreases, we obtain a record of the type reproduced in Figure 2. But if the height of the *F*-region fails to decrease until sunrise, we obtain records of the type reproduced in Figure 3.

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THE IONOSPHERE AT HUANCAYO, PERU, JANUARY, FEBRUARY, AND MARCH 1938

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This report is in continuation of that published in this JOURNAL (**43**, 169-171, 1938) on ionospheric data from continuous multifrequency ionospheric recordings at the Huancayo Magnetic Observatory for January, February, and March, 1938.

Table 1 contains mean hourly values of virtual height and critical frequency for the ionospheric regions for each hour during the first quarter of 1938. Also included are mean hourly values of the lowest frequency recorded (designated f_{min}) during the frequency-sweep from 16.0 to 0.516 mc second, which give a relative measure of absorption of radio signals in the lower ionosphere during the day. The data of Table 1 comprise recordings for each hour of the day and for every day of the month except for short intervals necessary for maintenance to the equipment.

Figure 1 represents graphically the data of Table 1. The following general discussion of characteristics seems pertinent:

(1) *F-region*—The virtual heights of the *F*-region for January were greater than those for February; likewise, the heights during February were generally greater than those during March. However, the range in heights for January was less than for February and, in turn, the February range was less than for March.

F-region critical frequencies show values during both January and March smaller than those for February. The range in f°_{F} for January was less than for February and for February was less than that for March.

(2) *F_1-region*—The virtual heights of the F_1-region for January and February showed little difference, but during March they were somewhat greater.

The critical frequencies of the F_1-region for January and February showed no appreciable difference but values during March were slightly lower.

(3) *E-region* —The virtual heights of the *E*-region for January were slightly greater than those for February and March, there being no appreciable difference between the latter. During February, however, they were somewhat greater than during both January and March which was also the case for the *F*-region.

(4) *Lowest frequency received*—Consideration of the lowest frequency recorded shows the values during February to be less than those for January and March. This could be interpreted as an indication that absorption in the lower ionosphere was less during February, in general, than during the other two months. However, since this factor varies somewhat with the transmitter-output and receiver-sensitivity as well as with atmospheric absorption, we think it advisable to defer rigid interpretation until more extended data are available.

Subsequent quarterly reports will include, in addition to the above,

TABLE 1—*Mean hourly values of ionospheric data, Huancayo Magnetic Observatory, January, February, and March, 1938*

January, 1938

EST	h_E	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$	f_{min}
h	*km*	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*
00	100		265	1.09		8.17	0.70
01	101		260	1.09		7.54	0.66
02	101		269	1.18		7.32	0.64
03	102		263	1.09		6.74	0.64
04	100		257	1.02		5.86	0.62
05	101		267	1.03		4.94	0.62
06	100		270	1.93		7.04	0.75
07	102		245	2.77		9.75	1.07
08	104	229	268	3.42	5.02	11.36	1.69
09	104	221	289	3.82	5.28	11.94	2.18
10	103	215	297	4.12	5.42	11.74	2.37
11	105	212	304	4.26	5.43	11.29	2.54
12	106	212	310	4.36	5.45	11.17	2.92
13	104	208	310	4.26	5.41	11.52	2.84
14	104	208	306	4.08	5.33	11.60	2.67
15	104	209	316	3.82	5 33	11.83	2.31
16	104	220	282	3.45	4.89	11.98	2.06
17	104		261	2.92		12.04	1.32
18	101		280	2.04		11.92	0.84
19	112		310	0.97		11.28	0.77
20	119		338	0.81		10.18	0.66
21	109		326	1.00		9.85	0.71
22	104		303	1.06		9.43	0.72
23	102		284	1.11		9.06	0.72

February, 1938

EST	h_E	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$	f_{min}
h	*km*	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*
00	98		250	1.30		9.71	0.74
01	98		233	1.16		8.94	0.82
02	99		239	1.24		8.02	0.64
03	97		241	1.07		7.13	0.67
04	99		240	1.02		6.68	0.63
05	99		250	0.91		5.43	0.66
06	99		274	1.77		6.67	0.75
07	100		245	2.71		10.00	1.03
08	101	226	257	3.36	4.87	11.93	1.51
09	102	224	274	3.80	5.10	12.78	1.77
10	101	216	283	4.08	5.48	12.97	2.09
11	102	212	291	4.28	5.61	12.67	2.40
12	102	209	291	4.39	5.61	12.22	2.54
13	101	209	289	4.27	5.54	12.32	2.33
14	102	208	286	4.11	5.38	12.31	2.36
15	101	210	278	3.85	5.16	12.28	1.95
16	101	217	267	3.43	4.65	12.17	1.62
17	100		252	2.87		11.81	1.14
18	99		280	2.05		11.20	0.96
19	100		331	0.97		10.85	0.80
20	104		362	0.81		9.97	0.73
21	104		346	1.05		10.65	0.70
22	103		313	1.16		9.99	0.74
23	99		278	1.21		10.20	0.73

March, 1938

EST	h_E	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$	f_{min}
h	*km*	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*
00	97		225	1.16		10.54	0.80
01	96		222	1.14		9.64	0.90
02	99		230	1.09		7.94	0.81
03	98		240	1.01		6.54	0.81
04	100		243	0.99		5.69	0.84
05	101		239	0.96		4.78	0.83
06	102		272	1.69		5.99	0.93
07	110		248	2.69		9.90	1.39
08	105	236	258	3.41	4.82	12.05	1.98
09	104	226	270	3.82	5.32	12.71	2.50
10	103	222	278	4.15	5.42	12.52	2.71
11	103	217	277	4.32	5.31	12.17	2.90
12	105	216	282	4.42	5.56	11.98	3.04
13	104	211	280	4.34	5.47	12.03	2.95
14	104	210	275	4.12	5.33	12.20	2.79
15	105	212	267	3.82	4.94	12.36	2.35
16	106	227	253	3.40	4.33	12 38	1.86
17	105		259	2.70		12.21	1.30
18	104		291	1.71		11.58	1.06
19	100		392	0.85		10.28	0.81
20	100		409	0.87		10.12	0.83
21	102		324	0.99		11.08	0.87
22	101		280	1.02		10.79	0.87
23	99		241	1.12		11.39	0.90

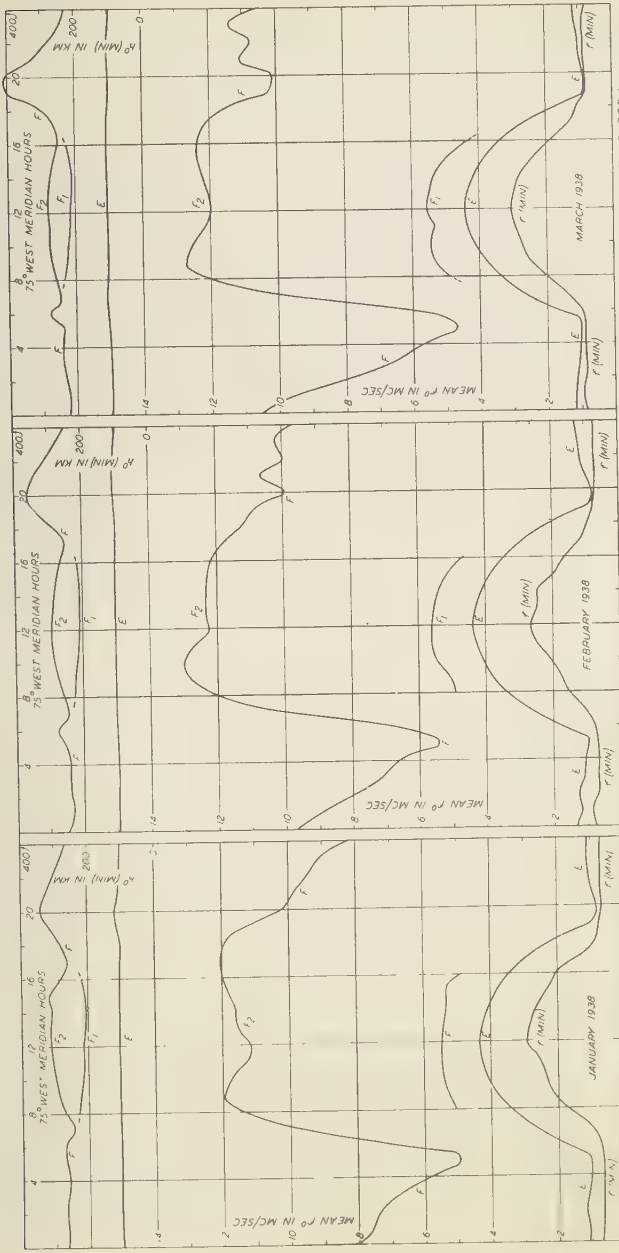

FIG. . MEAN CRITICAL FREQUENCY (f^0), MINIMUM VIRTUAL HEIGHT (h^0-MIN), FOR IONOSPHERIC REGIONS, JANUARY, FEBRUARY, AND MARCH, 1938, HUANCAYO, PERU

root-mean-square values of frequencies which will be more representative of average ionization than the normally-used means of critical frequencies.

Huancayo Magnetic Observatory,
Huancayo, Peru, May 16, 1938

ASYMMETRICAL CHARACTERISTICS OF THE EARTH'S MAGNETIC DISTURBANCE-FIELD

By E. H. Vestine

Abstract—Asymmetries in the Earth's magnetic disturbance-field are considered in relation to the asymmetries in the Earth's main field, using data of 32 stations. The auroral-zone curve of terrestrial magnetism, in north polar regions, is elongated in a direction roughly parallel to the elongation of isoclinic curves. It agrees roughly with the curve of maximum auroral frequency, as given by Fritz, except in regions where his auroral data were scanty. The curve appears to undergo regionally a small diurnal oscillation.

The amplitude of the disturbance diurnal variation (S_D) is approximately symmetrical with respect to the geographical equator in low latitudes, is zonal-symmetrical with respect to the auroral zone, and has a zero vertical component near the north pole given by the eccentric dipole. No change in amplitude with longitude has been detected, and it is concluded that induced earth-currents in the oceans contribute little to S_D.

The local time-phase of the mainly sinusoidal variation S_D shows a range of about four hours with longitude. But if in defining time the geographic north pole be replaced by the north pole given by the eccentric dipole, then at the auroral zone there is no significant variation in time-phase with longitude. This suggests that the auroral zone has a controlling and initiating influence over the world-wide electric currents responsible for S_D.

Average asymmetries in the geographical distribution of magnetic disturbance and aurora are compared. The average force-vectors for the daily means of disturbance are perpendicular to the average directions of homogeneous auroral arcs, to a high degree of approximation, in polar regions.

The S_D electric current-system of magnetic storms proposed by Chapman shows good general agreement with the extensive data here considered. Certain changes are suggested whereby the fit with observation may be improved.

1—*Introduction*

I. 1—The Earth's main field can be represented by a series of spherical harmonic terms, the first and much the largest term corresponding to a sphere of uniform magnetization. The central axis of symmetry of this sphere is the geomagnetic axis of the Earth. Magnetic disturbances tend toward symmetry relative to this axis, but since the geomagnetic axis is inclined to the geographic axis of rotation through an angle of 12°, and because of terms higher than the first in the spherical harmonic representation of the Earth's main field, magnetic disturbances may be expected to show certain significant departures from symmetry. These departures, not symmetrical relative to the geomagnetic axis, form the asymmetrical characteristics of disturbance. Due to their presence, magnetic disturbances may show variations in amplitude and time-phase with longitude.

I. 2—In a series of papers, Chapman [see 1, 2, 3, under references at end of paper] has studied the average characteristics of magnetic disturbances or storms, given by data averaged around parallels of latitude. As a result of these investigations he derived possible atmospheric-electric current-systems for magnetic storms, for an ideal Earth, with circular auroral zones, and having its geomagnetic and geographic axes coincident [3]. These current-systems give a good first approximation to those which may be appropriate to the real Earth; an improved approximation would require that the asymmetrical features of the Earth's disturbance-field be studied and taken into account.

I. 3—Chapman [2] noted small asymmetries in the geographical distribution of the annual averages of the daily means. The magnetic diurnal variations averaged for all days minus quiet days of the year also showed differences of several hours in local time-phase, for some stations distributed along the auroral zone. He ascribed the shift in time-phase as possibly due to the asymmetry of the geomagnetic and geographic axes; Chapman [4] had previously found through his analyses of the quiet-day diurnal variations the presence of magnetic effects not depending solely on local time, a fact also previously noted by Schuster [5].

I. 4—Asymmetrical features of the disturbance-field may also be of considerable interest in connection with theories of the cause of magnetic disturbances. It has been suggested that the electrical currents flowing above the Earth might be explained on the Stewart-Schuster dynamo-theory, involving horizontal motion of conducting air-layers of the upper atmosphere across the Earth's main field [5, 2]. In this theory the vertical (radially outwards) component of the main field is effective in the generation of electric current [4]; in north polar regions this component may vary about 20 per cent along a parallel of geomagnetic latitude. Also dependent on the field are the diamagnetic [6] and drift-current theories [7], although their successful applications in the explanation of a complicated disturbance-field must needs be notably limited in scope. Corpuscular [8] and ultra-violet light [9] theories of disturbance in their present forms do not as yet lend themselves conveniently to quantitative comparisons with observation, although the former affords perhaps the most promising approach in the study of the primary cause of magnetic disturbance; Chapman [8, 10], Hulburt [11], and McNish [12] have recently discussed this question. In the theory of Chapman and Ferraro [8], corpuscular streams from the Sun initiate magnetic disturbances on the Earth, the initial phase of a magnetic storm being associated with the advance of stream towards and about the Earth, while the main phase is supposed due in part to an encircling current-ring in the equatorial plane. In this connection it may perhaps be of interest to mention that the current-ring, if it exists, would appear to have an average radius of roughly two Earth-radii, as given by computations based on daily means of disturbance to be reported upon shortly; this radius may of course vary with the storm considered. According to Birkeland [13] there is an intake and outflow of electric current in the atmosphere, along the lines of force of the Earth's field, connected by roughly semi-circular auroral-zone currents; computations show that his model, in its present form, is in poor agreement with observation at distant points on the Earth north and south of the auroral zone. The immediate cause of the disturbance diurnal variation of magnetic storms seems likely to be due to an atmospheric-electric current-system roughly resembling that of the form proposed by Chapman; although this current-system is not unique [3] it would appear of interest to note, for points in different longitudes, the localized changes in form and intensity of the overhead portions of the current-system, in relation to asymmetries in the Earth's field. It might conceivably be possible to determine the cause of the current-system in this way, and thus to test such theories as have been proposed.

I. 5—From geometrical considerations the obliquity of the geomagnetic axis of the Earth should also be a factor of some importance causing asymmetry in the local geographical distribution of impinging charged

corpuscles of solar origin, for high latitudes, at different hours of local time. This is shown by the extensive studies of Störmer [14] and more recently by Lemaître and Vallarta [15]. There is also an observed diurnal variation of auroral frequency for which Vegard [16] has found the local times of evening maxima shifted in time-phase for stations in different longitudes, in north polar regions; these discrepancies were reduced by using magnetic time, defined by an hour-angle of the Sun measured at the geomagnetic north pole. Hulburt [17] found that this was by no means true for south polar regions and concluded that the phase-shifts could not be explained on this simple basis. The asymmetries shown by aurora may be of interest in connection with the asymmetries shown by the magnetic disturbance-field, since the distribution of electric currents in the atmosphere will be influenced by the space-distribution of ionized air.

I. 6—Up to the present it appears that little attempt has been made to study the average asymmetrical characteristics of the disturbance diurnal variation. This study forms the subject of inquiry of the present paper; the investigation is regarded as supplementary to a previous investigation of geomagnetic disturbances which was done in cooperation with Professor Chapman and which it is hoped to publish shortly. A considerable amount of the magnetic data here used will be more adequately described in that publication.

In the present investigation "auroral-zone curves" showing the geographical distribution of the intense, atmospheric, auroral-zone currents are approximately derived for the disturbance diurnal variation (to be subsequently denoted S_{Di}) and the daily means (D_{mi}), given by annual averages for international disturbed days minus quiet days, the subscript i relating to international disturbed days. These curves are compared with the curve of maximum auroral frequency as given by Fritz [18]. It is found that the auroral-zone currents flow nearly along the curve given by Fritz in some regions but about 6° of latitude farther south in the region north of eastern Russia, as compared with a radius of about 20° to 25° for the auroral zone. The auroral-zone curve of terrestrial magnetism is oval—almost elliptical—in shape, and is elongated approximately along the meridian joining the geomagnetic and geographic north poles, and nearly parallel to the direction of elongation of the isoclinic curves near the auroral zone. The amplitude of S_{Di} is zonal-symmetrical relative to the auroral-zone curve for S_{Di}, and no significant change of amplitude with the longitude of the station can be detected, whether for inland or island stations. It is concluded that the contribution of induced earth-currents to S_{Di} is about the same for land and sea areas; these currents, therefore, probably flow with greatest intensity in regions considerably below the Earth's surface, rather than in highly conducting oceanic areas.

S_{Di} at any station is approximately a sinusoidal function of local time. The times of maximum and minimum are not the same at stations in different longitudes. There is a variation of phase with longitude. The local time-phase of S_{Di} is earliest and latest, respectively, near geographic longitudes 0° to 10° east and 180° to 190° east, the range in phase in general being about four hours around any parallel of latitude. The speed of propagation of disturbance along the auroral-zone curve for S_{Di} shows two maxima and two minima. In northern latitudes of the

Earth, at least, the time-phase of S_{Dt} becomes very nearly the same at all points near the auroral zone, when magnetic time determined by the angular direction to Sun measured at the north pole of the eccentric dipole [19] is used. At points elsewhere on the Earth, the time-phase of S_{Dt} appears determined very nearly by the magnetic time-phase of S_{Dt} as noted at the auroral zone. This conclusion favors the suggestion previously made by Chapman and Whitehead [20], that "the facts may, however, be consistent with the view that the currents whose magnetic disturbing effect is observed during storms originate directly only in polar regions; one possibility is that some of the polar electric currents find return paths in conducting regions of the atmosphere in middle and low latitudes," the world-wide magnetic variation S_{Dt} being mainly initiated by events occurring near the auroral zone. Mathematical examination of this possibility is desirable and it is hoped to attack this problem at an early date.

An additional feature of some interest appearing through the present investigation was that the average directions of homogeneous, quiescent, auroral arcs are perpendicular to the average vector D_m given by the daily means of disturbance to a high degree of approximation, for nine widely distributed stations in north polar regions, suggesting a very direct relationship between the two phenomena. The magnitude of D_m depends mainly on geomagnetic latitude, but the available data show also that its magnitude may depend on the value of the vertical component of the Earth's field. The values of D_m are relatively large in the region near the local north magnetic pole. This result appears incompatible with a dynamo-theory involving radial compression followed by expansion of highly conducting regions of the upper atmosphere, during magnetic storms, as has been suggested to explain the electric currents required for the magnetic storm-time variation. A dynamo-theory of D_m depending on the vertical component of the Earth's field would necessarily involve ionized regions having a horizontal component of motion relative to the Earth.

II—*Magnetic data*

II. 1—In the study of asymmetrical characteristics of the Earth's disturbance-field extensive data for well-distributed stations are required. The observational data consist mainly of the daily means D_{mt} and the disturbance diurnal variations S_{Dt}, given by international disturbed days minus international quiet days, averaged in most cases over a period of one year, or in a few cases of very nearly one year. Use is also made of values of the daily means D_m and of S_D, for all days minus quiet days, derived by Chapman [2] for stations of the First International Polar Year, 1882-83; included also are Lüdeling's [21] data for summer of 1883 and data for S_{Dt} given by Stagg [22].

II. 2—Chapman [2] has shown that the average characteristics of magnetic disturbance do not differ much in general type, within wide ranges in the intensity of disturbance. Although the foregoing sets of data are derived for various epochs, the general average types of disturbance are rather similar in character. Extensive data for the Second International Polar Year, 1932-33, and for the year 1933 form the basic set for the investigation; data for other epochs are considered and used as supplementary. In studying the amplitudes of disturbance care has

been used in selecting data derived as nearly as possible for the same epoch. This is a matter of some importance since the amplitude and phase of the annual average of disturbance vary somewhat with the epoch considered. The geographical distribution of the high-latitude stations used is shown in Figure 1; positions of other stations used are included in Table 1.

TABLE 1—*List of magnetic stations used*

Station	Φ	Λ	Ψ	φ	λ
	°	°	°	°	°
Thule	88.0	359.3	− 0.6	76.5	291.1
Kingua Fiord	78.1	3.5	− 1.7	66.6	292.7
Godhavn	79.9	32.9	−17.6	69.2	306.5
Scoresbysund	75.8	81.4	−36.2	70.5	338.0
Godhaab	74.8	29.8	−13.1	64.2	308.3
Cape Thordsen	74.5	131.7	−48.0	78.5	15.7
Chesterfield Inlet	73.5	324.5	14.9	68.3	269.3
Jan Mayen	73.4	96.5	−37.5	71.0	351.7
Franz Josef Land	71.5	153.3	−32.2	80.3	52.8
Bear Island	71.1	124.1	−37.9	74.5	19.2
Juliannehaab	70.8	35.6	−13.8	60.7	314.0
Fort Rae	69.0	290.9	24.1	62.8	243.9
Point Barrow	68.6	241.3	33.0	71.3	203.3
Tromsö	67.1	116.8	−30.8	69.7	18.9
Bossekop	66.6	120.4	−30.1	70.0	23.2
Petsamo	64.9	125.8	−27.6	69.5	31.2
Matotchkin Shar	64.8	146.5	−22.4	73.3	56.4
Novaya Zemlya	64.5	143.3	−23.1	72.4	52.6
Sodankylä	63.8	120.0	−26.7	67.4	26.7
Dickson	63.0	161.5	−12.8	73.5	80.4
Lerwick	62.6	88.6	−23.6	60.1	358.8
Sagastyr	62.2	189.6	6.6	73.4	126.6
Meanook	61.8	301.2	17.1	54.6	246.7
Sitka	60.0	264.5	21.4	57.0	224.7
Eskdalemuir	58.5	82.9	−20.4	55.3	356.8
De Bilt	53.8	89.4	−18.9	52.1	5.2
Seddin	52.4	97.0	−18.9	52.3	13.0
Cheltenham	50.1	350.5	2.4	38.7	283.2
Tucson	40.4	312.2	10.1	32.2	249.2
Honolulu	21.0	266.5	12.3	21.3	201.9
Huancayo	− 0.6	353.8	1.3	−12.0	284.7
Watheroo	−41.8	185.6	1.3	−30.3	115.9

III—*The auroral-zone curves of S_{Dt} and D_{mt}*

III. 1—As was first shown by Birkeland [13], the disturbance-field near the auroral zone in the case of magnetic bays is at times similar to that given by an intense and concentrated electric current flowing within the atmosphere and along the auroral zone, at heights 100 to 400 km above the Earth. Additional estimates by the writer, to be reported upon separately from this paper, give heights roughly about 150 km above the Earth, in good agreement with similar results recently found by McNish [23].

III. 2—Using the method of Birkeland and the disturbance-vectors of S_{Dt} at the three stations, Bear Island, Tromsö, and Sodankylä (Fig. 1), conveniently located relative to the auroral zone, the height, position, and intensity of a hypothetical linear current flowing above the Earth

can be estimated for this region. Neglecting the effect of induced earth-currents, at the times of morning and evening maximum change in the horizontal component of S_{Dt} at Tromsö, the heights of current found were roughly 300 km for both times of day. These estimates were made using a simple diagram showing to scale the positions of the stations on a line representing the Earth's surface, and drawing perpendiculars from the directions of the force-vectors at the three stations. The magnitudes of the vectors were in rough agreement with the position and

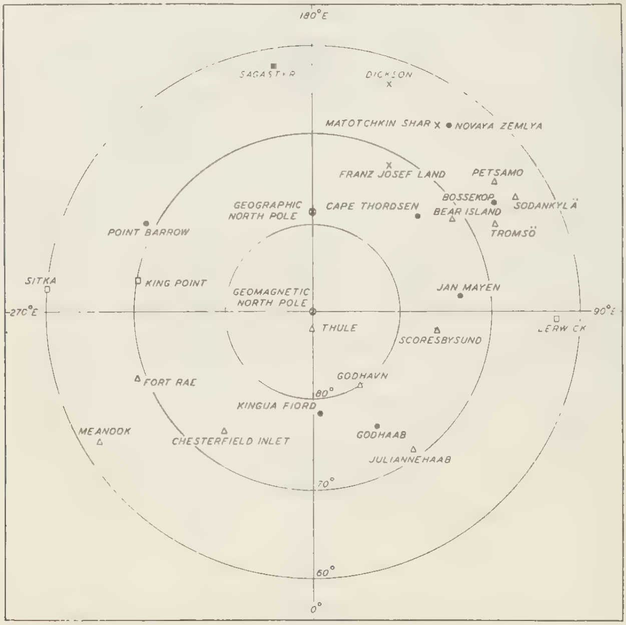

FIG. 1—MAGNETIC STATIONS USED
• = FIRST INTERNATIONAL POLAR YEAR, 1882–83; Δ = SECOND INTERNATIONAL POLAR YEAR, 1932–33; x = YEAR 1933; □ = OBSERVATORIES VARIOUS EPOCHS, 1906–33

height of current. This estimate of height will of course be too high due to neglecting the influence of induced earth-currents [3, 23], but we assume that the horizontal distance on the Earth from station to current is approximately correct. The error in computing the horizontal distance from the disturbance-vector at one station, assuming a constant height of current, will be greater when the distance from station to current is greater; it should be small when this distance is small. The accuracy will also be affected by the degree of approximation afforded in using a linear current to represent the distribution of current near the auroral zone. In making estimates of the horizontal distance to the current, using this method, it is desirable to use values of the vectors for S_{Dt} which are large as compared with those for other times of day; at other times of day the estimates are more likely to be affected by extra-zonal currents which must leave or reenter the auroral-zone current in preserving continuity of current-flow.

III. 3—We first derive an auroral-zone curve for S_{Dt}. We assume that the height of the auroral-zone current is 300 km, and use the directions of the disturbance-vectors given by the X' and Z' geomagnetic components of S_{Dt}, at single stations distributed very near the auroral-zone current. The geomagnetic components X' and Y' of the horizontal force are parallel and perpendicular to the geomagnetic meridian, respectively, positive northwards and eastwards, and Z' is the vertical component positive when downwards. In Table 2 are given the stations used, their geomagnetic coordinates, the geomagnetic components of S_{Dt} at the times of dawn and evening maximum and the computed horizontal distances x to current measured southwards along the geomagnetic meridian through the station. It will be noted that corresponding values of x for dawn and evening periods are in good agreement, showing little difference between the lateral displacements of current for the two times of day; these currents flow westward at dawn and eastward in the evening.

TABLE 2—*Horizontal distance x to current given by* S_{Dt}

Station	Φ north	Λ east	Dawn maximum				Evening maximum				Φ′ north
			$\delta X'$	$\delta Z'$	$\delta Z'/\delta X'$	x	$\delta X'$	$\delta Z'$	$\delta Z'/\delta X'$	x	
	°	°	γ	γ		*km*	γ	γ		*km*	°
Tromsö	67.1	116.8	−215	+ 34	−0.16	+ 48	+147	− 2	−0.00	0	67.1
Sodankylä	63.8	120.0	−138	− 92	+0.67	−200	+ 92	+ 64	+0.70	−210	63.8
Petsamo	64.9	125.8	−203	+ 29	−0.13	+ 40	+136	+ 25	+0.18	− 50	67.0
Matotchkin Shar	64.8	146.5	−138	+100	−0.72	+230	+110	− 99	−0.90	+270	70.0
Dickson	63.0	161.5	−156	+ 91	−0.58	+170	+126	− 70	−0.56	+170	69.0
Fort Rae	69.0	290.9	−117	+132	−1.13	+340	+115	−104	−0.91	+270	70.8
Meanook	61.8	301.2	− 88	− 79	+0.90	−270	+ 64	+ 55	+0.86	−260	63.6
Juliannehaab	70.8	35.6	−101	+122	−1.21	+360	+116	−115	−1.00	+300	70.8

Additional points through which the auroral-zone curve would approximately pass were obtained, using the values of the horizontal components of S_D given by Lüdeling. The stations used were Bossekop, Novaya Zemlya, Point Barrow, Fort Rae, Sagastyr, and Sodankylä (Fig. 1). Using the data for stations of Table 2, the maximum range in the horizontal force was plotted as a function of x. Corresponding ranges in horizontal force were next derived for Lüdeling's data; a constant of proportionality 2.1 correcting approximately for the difference in the average intensity of disturbance for the two sets of data was next derived. No vertical-force data were available for the Sagastyr station so that the curve giving the horizontal-force range as a function of x gave two values $x = +5°.3$ or $-3°.7$ of latitude. The components of S_D in the horizontal plane at Sagastyr closely resemble those for Point Barrow, north of the auroral zone, so that the value $x = -3°.7$ is very probably the one to be taken and has been adopted. Using directions of auroral-zone currents, a mean smoothed curve was then drawn among the points determined from observations and is represented by curve 4 in Figure 2. The values Φ′ in Table 2 give the approximate appropriate magnetic latitudes of the stations if curve 4 were moved into coincidence with the circle of magnetic latitude 67°.

The auroral-zone curve for S_{Dt}, as derived here, should afford a good

first approximation to the true form of the curve; it would appear probable that the error is greatest near geomagnetic longitudes about 0° and 210° east, regions for which magnetic data are not at present available.

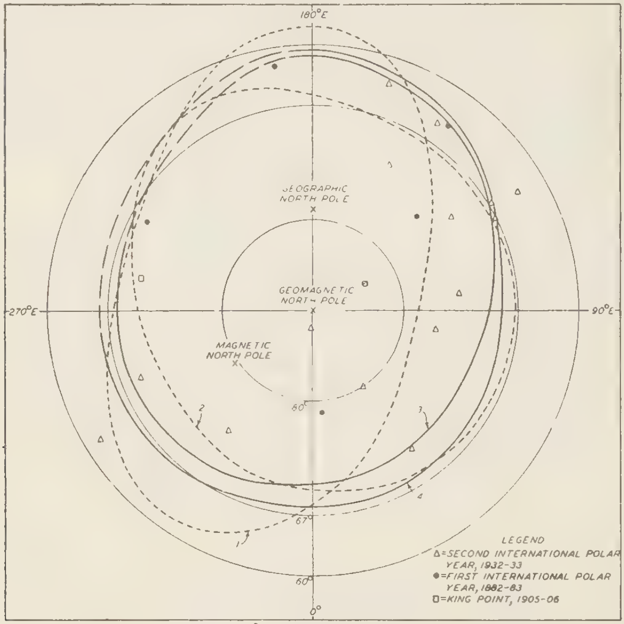

FIG. 2—CURVES OF [1] INCLINATION 80° NORTH FOR 1922, [2] OF MAXIMUM AURORAL FREQUENCY (FRITZ) COMPARED WITH PROJECTIONS ON EARTH'S SURFACE OF CONCENTRATED AURORAL-ZONE CURRENTS COMPUTED ON BASIS INFINITE LINEAR CURRENT, [3] FROM DAILY MEANS (D_m), AND [4] FROM MEAN POSITIONS GIVEN BY DAWN AND EVENING MAXIMUM (OR MINIMUM) OF DISTURBANCE DIURNAL-VARIATION (S_D)

III. 4—Curve 3 of Figure 2 was derived applying similar methods and assumptions to data for the daily means D_{mi} and values of D_m. The stations used and the values of x are given in Table 3.

TABLE 3—*Horizontal distances x to current given by D_{mi}*

Station	Φ north	Λ east	δH	δZ	$\delta Z/\delta H$	x
	°	°	γ	γ		km
Tromsö	67.1	116.8	−44	− 4	+0.09	− 30
Bossekop	66.6	120.4	−28	− 7	+0.25	− 75
Sodankylä	63.8	120.0	−25	−17	+0.68	−200
Petsamo	64.9	125.8	−32	− 8	+0.25	− 75
Matotchkin Shar	64.8	146.5	−41	+ 9	−0.22	+ 70
Dickson	63.0	161.5	−36	+ 9	−0.25	+ 75
King Point	70.2	259.6	−52	+39	−0.75	+220
Fort Rae	69.0	290.9	50	+24	−0.48	+140
Chesterfield Inlet	73.5	324.5	−28	+41	−1.5	+440
Juliannehaab	70.8	35.6	−26	− 5	+0.19	− 60

The disturbance-field due to D_{mt} resembles less closely that of a linear current than does the field due to S_{Dt}, in regions near the auroral zone. It therefore appears that less significance is to be attached to the auroral-zone curve derived using values of D_{mt}. However, it seems likely that the maximum concentration of auroral-zone currents responsible for D_{mt} occurs several degrees of latitude farther northwards than in the case of S_{Dt}.

III. 5—Curves 3 and 4 derived in § III. 3 and § III. 4 were obtained using only the *directions* of the disturbance-vectors at the various stations, as given by the ratios of the vertical to the horizontal components of the force. Added weight is given to our calculations if it appears that the *magnitudes* of the components of force show zonal symmetry relative to the computed curves and vary systematically with the horizontal distances x from station to auroral-zone curve, whatever the longitude of the station.

In making this test it is convenient to suppose curve 4 is a circle of geomagnetic latitude 67°. We then adjust the geomagnetic latitudes of the stations near the auroral zone in order that the distances x remain unaltered, thus obtaining new values Φ' for the geomagnetic latitudes of the stations (Tables 2 and 3). This adjustment to a circular auroral-zone was made for stations in geomagnetic latitudes 62° to 72°; at greater distances from the auroral-zone curve this adjustment is of little importance since the field of the auroral-zone currents falls off less rapidly with distance, at points more distant from the auroral zone.

In Figure 3 are shown the variations with latitude found in the maximum magnitudes of the components of S_{Dt} for dawn, noon, evening, and midnight periods. Smoothed curves have been drawn among the points given by observation. On the whole, the points conform very well to the smoothed curves in the case of all three components of the force, and in the region near the auroral zone the disturbance-field is thus zonal-symmetrical relative to the auroral-zone curve for S_{Dt}. It can also be shown that for this region the magnitudes of the geomagnetic northward and vertical components are roughly compatible with the hypothesis of a concentrated current flowing along the auroral-zone curve, at times of maximum change in these components of the force. It would also appear that the derivation of the auroral-zone curve, as given here, is independent of the assumption of a linear-current hypothesis, but depends only on the shape of the disturbance-field.

It should be mentioned that Figure 3 presents only data for maxima and minima in the geomagnetic components of S_{Dt}; additional orthogonal horizontal components, in general comparatively small, are not shown.

Similar curves showing the variations of D_{mt} relative to the position of the auroral-zone curve for D_{mt} would also show evidence of zonal symmetry.

III. 6—Curve 4 of Figure 2, the auroral-zone curve for S_{Dt}, roughly resembles curve 2, that of maximum auroral frequency as given by Fritz [18], based on auroral observations for the years 1700-1880. The most noteworthy departures are near longitudes 170° east and 290° east, where curve 4 extends several degrees farther southwards than curve 2. In shape, curve 4 is oval, almost elliptical, and is elongated in a direction roughly parallel to the direction of elongation of curve 1, that of equal magnetic dip (80°). The lack of symmetry shown by curves 3 and 4

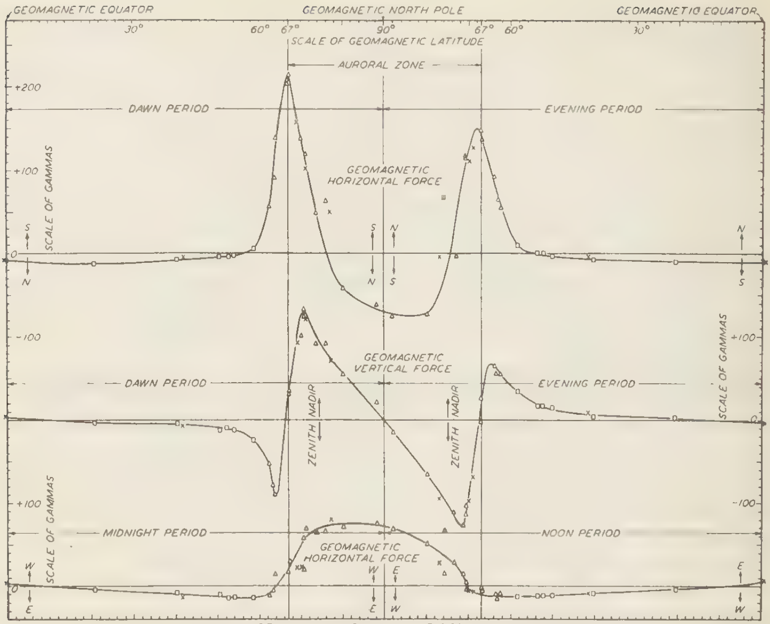

FIG. 3—VARIATIONS WITH LATITUDE OF MAXIMA AND MINIMA OF GEOMAGNETIC COMPONENTS OF DISTURBANCE DIURNAL-VARIATION FOR INTERNATIONAL DISTURBED MINUS QUIET DAYS (S_{D_i})[DATA FOR MAGNETIC LATITUDES 62°N TO 72°N ARE ADJUSTED IN LATITUDE RELATIVE TO CIRCULAR AURORAL ZONE]
Δ=SECOND INTERNATIONAL POLAR YEAR, 1932-33; ×=YEAR 1933; □=OBSERVATORIES VARIOUS EPOCHS, 1911-33

relative to the geomagnetic axis probably reveals the most marked asymmetrical feature of the Earth's magnetic disturbance-field.

Curves 3 and 4 are derived using the basic magnetic data for days of considerable magnetic disturbance, the five most disturbed days of each month, averaged for the year. The data for all days minus quiet days of the Polar Year 1882-83 as derived by Chapman [2] and for selected disturbed days minus quiet days given as derived by Lüdeling [21] show good general agreement in the type of average characteristics and with the auroral-zone curves deduced here, in regions where data are available for both Polar Years. This agreement is most clearly shown by the force-variations at Fort Rae, Bossekop, and Sodankylä of the Polar Year 1882-83 as compared with those for Fort Rae, Tromsö, Petsamo, and Sodankylä of the Polar Year 1932-33, despite the differences in the average intensities of disturbance represented by the sets of data. In the case of magnetic bays, the "current-arrows" and estimates of position of current made by Birkeland [13], and more recently by McNish [23], for certain regions near the auroral zone, also appear compatible with the average approximate position of the auroral-zone curves here derived. On individual moderately disturbed days the auroral-zone currents would of course vary in lateral position through several degrees of latitude; during days of magnetic storm, as is well-known, the auroral-zone curve may expand to attain a position several degrees of latitude south of its average position, and subsequently contract.

As an instance of such an expansion, the mean hourly disturbance-vectors for 16^h GMT of the magnetic storm of May 1, 1933, appear to show that the general shape of the auroral-zone curve is preserved, at least in certain regions, during the expansion. Averaged for this hour the concentrated auroral-zone currents, on a linear-current hypothesis, were about 1° of latitude north of Meanook (Fig. 1), where the decrease in the component X' was about 700γ and the decrease in the vertical component 200γ; the concentrated eastward currents were practically overhead at Lerwick, where the increase in the component X' was about 570γ and the decrease in the vertical component 50γ. Near Meanook and Lerwick the expansion of the auroral zone was thus 3°.2 south and 6°.0 south, respectively, of the average curve for S_{Dt}, the discrepancies in the amounts of expansion for the two stations being thus only about 300 km.

III. 7—It is at present somewhat difficult to determine whether the auroral-zone curve (say the mean for S_{Dt} and D_{mt}), also accurately describes the average curve of maximum auroral frequency for international magnetically-disturbed days of the year. An opportunity for making this comparison will be afforded when the extensive auroral observations of the Polar Year 1932-33 become available for study. Present indications, though necessarily somewhat qualitative, make it appear probable that the curve derived from terrestrial magnetism will afford a better approximation to the curve of maximum auroral frequency than that of Fritz. In his great memoir on aurora, Fritz used scattered observations for various epochs of the years 1700 to 1880 in deriving the curve. In general, the agreement of this curve with the auroral-zone curve of terrestrial magnetism is better in regions for which Fritz had extensive data; few auroral data were available to Fritz for stations in northeastern Russia, where the discrepancy between his curve and the auroral-zone curve of terrestrial magnetism is greatest. In the region near Fort Rae and Meanook, the discrepancy is also large. Aurorae, often of considerable intensity, were observed chiefly in the north at Meanook during the hours 4^h to 7^h, GMT, on 22 out of a possible 23 of the 30 international disturbed days of January to June, 1933, inclusive, seven nights being cloudy. A preliminary estimate by Stagg [24] places the average curve of maximum auroral frequency at the station Fort Rae. In this region it would therefore appear that the true curve of maximum auroral frequency for disturbed days agrees more closely with the auroral-zone curve of terrestrial magnetism than with the curve of Fritz.

In 1741 Hiorter and Celsius noted an intimate connection between magnetic and auroral disturbances [18], a finding since confirmed by many writers. On the whole it appears highly probable that the average auroral-zone currents flow with highest intensity where the ionization associated with frequent auroral displays also appears with highest average intensity. The auroral-zone curve of terrestrial magnetism therefore probably affords an approximation to a curve of maximum auroral frequency or intensity, corresponding to international disturbed days; the curves for frequency and intensity are of course not necessarily coincident. It should be carefully noted that the position of the auroral-zone curve is appropriate to the two daily times of maximum magnitude in the magnetic disturbance S_{Dt}; the curve in the Figure does not necessarily give the shape nor position of the complete auroral-zone curve

in relation to the Earth, at a given instant of universal time, although less reliable estimates using disturbance-vectors of S_{Dt} for other hours of day seem compatible with this view, except possibly at times when the auroral-zone currents reverse in direction, the estimates then being wholly unreliable.

III. 8—*Apparent diurnal oscillation of the auroral-zone curve for S_{Dt}*—Improved estimates of the distances x to current, using the method applied for Table 2, should be obtained employing horizontal components $\delta X''$ of disturbance perpendicular to the auroral-zone curve, instead of using the corresponding geomagnetic components $\delta X'$. In Table 4 are given the values x (positive southwards) computed on this basis, at times of morning and evening maximum disturbance. As before, the linear current is assumed at a height of 300 km; the computed distances x will be directly proportional to the height assumed.

TABLE 4—*Horizontal distances x to current from S_{Dt}*

Station	Φ'	Dawn maximum				Evening maximum				
		Local time	$\delta X''$	$\delta Z'$	x	Local time	$\delta X''$	$\delta Z'$	x	$\triangle x$
	°	*h*	γ	γ	*km*	*h*	γ	γ	*km*	*km*
Tromsö	67.1	1.5	−224	35	47	16.5	156	− 2	+ 4	43
Petsamo	67.0	1	−209	30	42	17	140	+13	− 27	69
Matotchkin Shar	70.0	2	−138	89	192	17	122	−35	+ 87	115
Dickson	69.0	3	−152	80	158	17	132	−17	+ 39	119
Fort Rae	70.8	6	−102	120	351	16	114	−47	+123	228
Juliannehaab	70.8	4	−115	89	231	14	118	−28	+ 72	159

The values of the changes $\triangle x$ are always positive giving the zonal currents farther south at dawn than at evening, the changes being small. The error seems likely to be less for a station very near the auroral-zone curve ($\Phi' = 67°$). The mean of the values of $\triangle x$ is 122 km.

In Figure 3 we also note that the smoothed curves for the components of S_{Dt} in the directions X' and Z' show a displacement of the dawn maximum to the south of the evening maximum. It therefore appears possible that the average auroral-zone curve for S_{Dt} undergoes a small diurnal regional change in radius depending on the position of the Sun, the radius being slightly larger in the morning than in the evening.

The experiments of Birkeland, using charged particles in the presence of a magnetized sphere, showed that the radius of the auroral zone was somewhat smaller on the evening than on the morning side of the sphere, in the case of positively-charged particles. Although this may suggest an explanation of the change in radius of the auroral-zone curve, based on a spiral form of the curve due to positively-charged particles, corpuscular theories of magnetic disturbance require streams of charged particles of both signs, initially, at least, nearly neutral electrostatically [8]. Vegard [25] has suggested the use of alpha particles for the explanation of homogeneous auroral arcs and their average diurnal oscillation in lateral position and direction. Although the position of the auroral-zone curve seems likely to be explained best on the basis of incoming charged

particles, the establishment of this fact would require further detailed and difficult examination. Störmer has also shown that the regional lateral position of the auroral zone, in the case of rare streams of charged particles, would depend on the inclination of the Earth's geomagnetic axis relative to the equatorial plane including the Earth's center and the Sun.

It should also be noted that the apparent oscillation of the auroral-zone curve for S_{Dt} may be due to other causes, such as differences in the distribution of extra-zonal currents above regions where the morning and evening maxima in the magnitude of the force appear, and also upon air-movements.

IV—*Variation in the time-phase of S_{Dt} with longitude*

IV. 1—The data of Figure 3 show that S_{Dt} undergoes little significant change in amplitude with longitude. This is by no means true with respect to the local time-phase of S_{Dt}, a fact towards which attention has been drawn previously by Chapman [2] and more recently by Goldie [26].

The asymmetrical features of the local time-phase are conveniently studied by comparing the local times of maximum, minimum, and zero values in components of S_{Dt}, for stations in various longitudes. In Figure 4 are shown the variations in local time-phase found in the geomagnetic components of S_{Dt} in the directions X', Y', and Z'. The phase of S_{Dt} also varies somewhat with magnetic latitude, particularly in the region near and just south of the auroral zone. For this reason three groups of stations are used. The first group includes stations north of or at the auroral zone, the second those very near the auroral zone, and the third comprises stations in lower latitudes. The magnitudes of the components X' and Z' of S_{Dt} have morning and evening maxima, while in general for the component Y' these occur near the noon and midnight periods [2]. The magnitude of the component Y' in general is greatest near the times of zero-value of the components X' and Z', except in the region near the auroral zone. The local times given here for the component Y' are for this region, those actually shown by the eastward component taken in a direction parallel to a tangent to the auroral-zone curve; they are not accurately determined because this component is in general small since it undergoes a reversal in phase near the auroral zone (Fig. 3).

The time-phases of orthogonal horizontal components of S_{Dt} will depend on the directions in which these are taken; the mainly geomagnetic character of the field enables the use of geomagnetic components.

In regions (Fig. 3) near which the geomagnetic components of S_{Dt} are small and reverse in phase, less significance can be attached to the local times of maximum and zero magnitudes.

Smoothed curves have been roughly drawn among the points given by observation, giving only a rough probable approximation to the true trend of the curve since the scatter in the points is unfortunately often considerable. It appears likely that the spread among the points would be reduced if the stations in each group were located in narrower belts of geomagnetic latitude. The discrepancies would probably also be reduced if average values could be derived over a period of several years. In equatorial regions, also, the amplitude of S_{Dt} is only about one-quarter of the amplitude of the quiet-day diurnal variation, for example, at

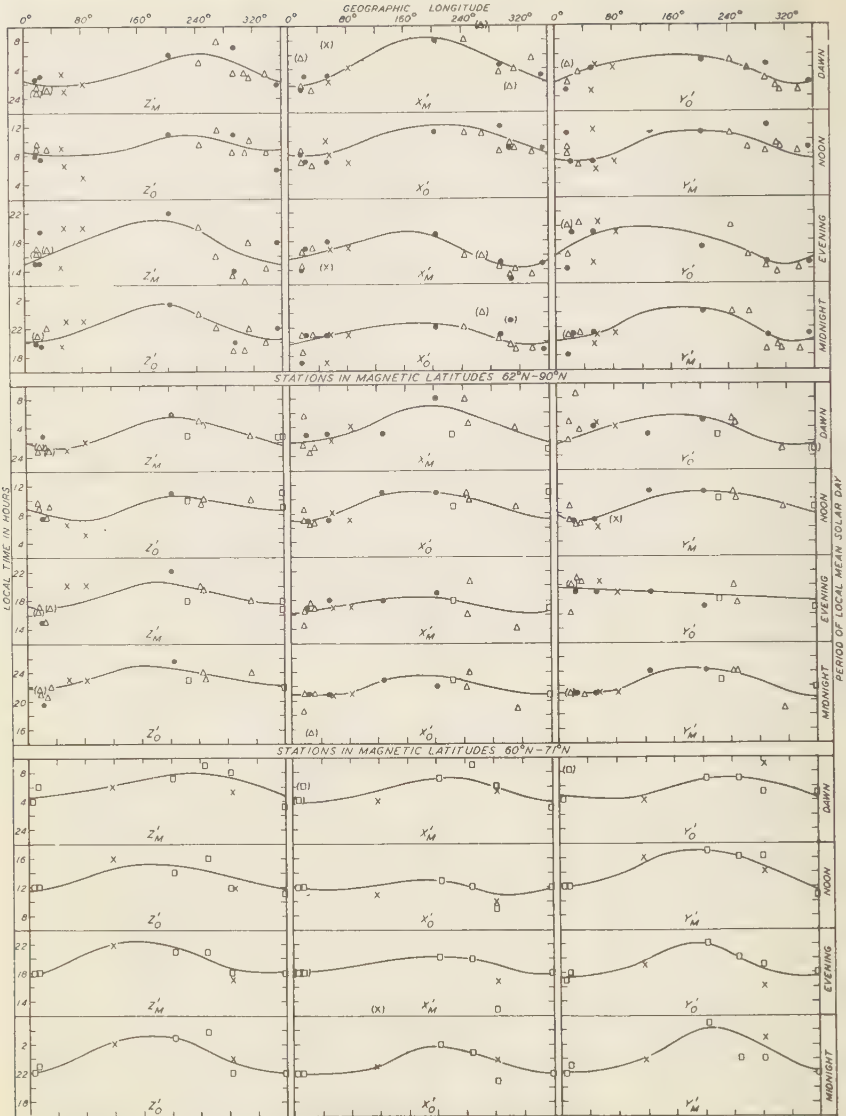

FIG. 4—CHANGES IN LOCAL TIME-PHASE OF GEOMAGNETIC COMPONENTS OF DISTURBANCE DIURNAL-VARIATION (S_D) WITH GEOGRAPHIC LONGITUDE

● = FIRST INTERNATIONAL POLAR YEAR, 1882–83; Δ = SECOND INTERNATIONAL POLAR YEAR, 1932–33; X = YEAR 1933
□ = OBSERVATORIES VARIOUS EPOCHS, 1911–33; ( ) = SOMEWHAT UNCERTAIN

[Z', X', AND Y' = VERTICAL, GEOMAGNETIC NORTHWARD, AND GEOMAGNETIC EASTWARD FORCE, WITH SUBSCRIPTS M AND O REFERRING TO TIMES MAXIMUM MAGNITUDE AND ZERO MAGNITUDE RESPECTIVELY]

Huancayo, so that S_{Dt} is derived as the difference of two relatively larger and nearly equal quantities. Corrections applied for non-cyclic change were also relatively important in this region.

In general the smoothed curves of Figure 4 show rough similarity for all components of the force. The curve for Y'_0 for the evening period is an exception, in the second group of stations. As previously indicated, the accuracy for this region is considerably less than for other components.

On an average, the local time-phase is earliest and latest, respectively, near longitudes 0° to 10° east and 180° to 190° east. The mean range in phase from the 12 curves for the group of stations in geomagnetic latitudes 62° to 90° north is 4.6 hours, for 60° to 71° north is 3.7 hours, and for 0° to 50° north is also 3.7 hours, including the station Watheroo in southern latitudes. The average range in local time-phase along any parallel of geomagnetic latitude is thus about four hours, although this range may be greater in very high latitudes.

IV. 2—The variations in local time-phase with longitude have been

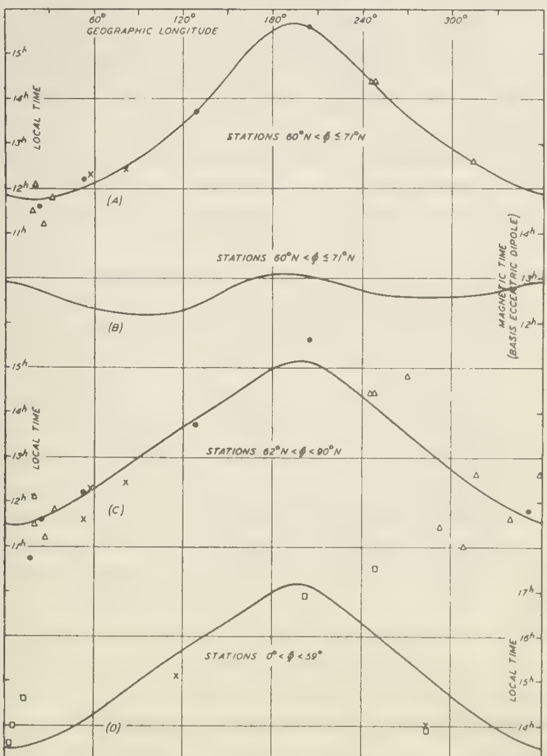

FIG. 5—VARIATION IN AVERAGE TIME-PHASE FOR DISTURBANCE DIURNAL-VARIATION (S_D) WITH GEOGRAPHIC LONGITUDE

•=FIRST INTERNATIONAL POLAR YEAR, 1882-83; Δ=SECOND INTERNATIONAL POLAR YEAR, 1932-33; X=YEAR 1933; □=OBSERVATORIES VARIOUS EPOCHS, 1911-33

shown to be roughly similar in each geomagnetic component of S_{Dt}. In Figure 5-*A* is given the variation with longitude obtained by meaning the eight local times of maximum and zero magnitudes of the components X' and Z' for stations in geomagnetic latitudes 60° to 71° north, very near the auroral zone; the data used are those of Figure 4. The points given by observation here conform more closely to the smoothed curve than for the individual curves of Figure 4. This smoothed curve should afford a good approximation to the average variation in local time-phase along the auroral-zone curve for S_{Dt}.

As shown by Bartels [27], the Earth's main field is closely approximated by the eccentric dipole at the magnetic center of the Earth ($\phi = 6°.5$ north, $\lambda = 161°.5$ east), about 340 km from the geographic center. The axis of this dipole is directed parallel to the Earth's geomagnetic axis and pierces the Earth's surface in points given by the geographical coordinates ($\phi = 80°.1$ north, $\lambda = 277°.3$ east) and ($\phi = 76°.3$ south, $\lambda = 121°.2$ east).

The hour-angle of the Sun is given by local time. We can define a time t_e as given by the corresponding angle measured with reference to the axis of the eccentric dipole. The values of t_e for points in various geographic longitudes along the auroral-zone curve for S_{Dt} may then be computed for events occurring according to local time at these points. From Figure 5-*A* we thus obtain the curve Figure 5-*B* illustrating the variation of the corresponding values of t_e with geographic longitude. The range in the average value of t_e along the auroral-zone curve is less

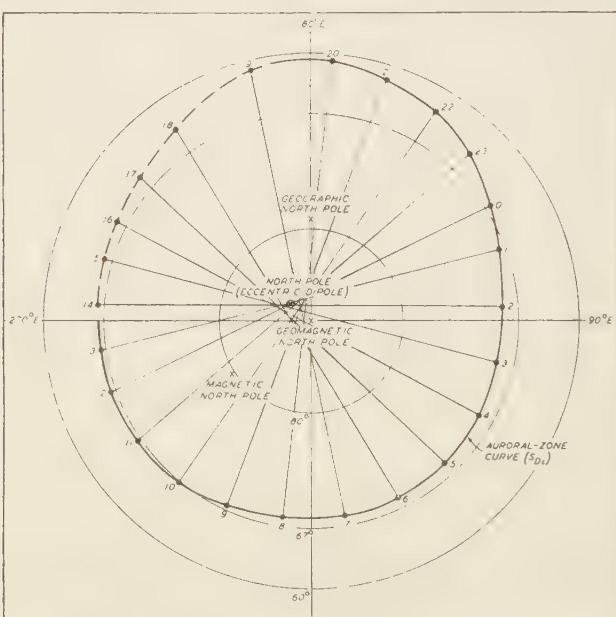

FIG. 6—SUCCESSIVE POSITIONS OF MAXIMUM WESTWARD CURRENT-FLOW ALONG AURORAL ZONE, GMT, INTERNATIONAL DISTURBED DAYS (S_{Dt})

than one hour, and probably therefore not greater than the error of observation.

In Figure 6 the approximate successive average positions of the maximum westward currents flowing along the auroral zone are indicated according to GMT. An arbitrary constant value of ten hours has been subtracted from each of the values given by Figure 5-*A*, so that the position of maximum westward current is on the Greenwich meridian at $1^h.9$ local time, taken to be required by observation. The close dependence upon t_e is shown by the fact that lines drawn joining the points marked on the curve 12 hours apart all intersect very close to the point representing the north pole given by the eccentric dipole. Relative to this pole the average disturbance along the auroral zone has an angular velocity which is nearly uniform. The speed of propagation of the disturbance, measured relative to the Earth, is apparently greater between 18^h and 19^h than for other parts of the curve; it appears likely that this may be a result of inaccuracy, due to a deficiency of stations between Point Barrow ($\lambda = 203°.3$ east) and Sagastyr ($\lambda = 126°.6$ east).

At low-latitude stations the corrections to be applied to obtain t_e are very small. At stations in very high latitudes these corrections may be large. However, the phase of S_{Dt} in such regions seems most simply explained as mainly determined by the intense auroral-zone currents.

In Figure 5-*C* are given points representing the average local times of maximum and zero magnitudes of the components X' and Z' of S_{Dt}, for stations in geomagnetic latitudes 62° to 90° north; in this range are also included a number of the stations used for Figure 5-*A*. Assuming that the disturbance at the auroral zone depends exactly on t_e (taken to be 13^h), the corresponding values of local time at the auroral-zone curve for S_{Dt} were computed and are represented as a function of geographic longitude by the curve in Figure 5-*C*. In Figure 5-*D* a corresponding comparison is effected for stations in latitudes 0° to 59° north, t_e at the auroral zone taken to be 15^h, thus assuming that the planes of symmetry of the current-system flowing above lower latitudes shifted through an angular distance of two hours relative to the planes of symmetry at the auroral zone.

It thus appears that the average time-phase of S_{Dt}, from the equator to the poles, can be simply explained as depending mainly on the time t_e for disturbances occurring at the auroral zone. This may mean that the electromotive forces giving rise to the world-wide atmospheric-electric current-system S_{Dt} originate, in most accentuated form, mainly near the auroral zone. The greater part of the current would flow across the polar cap in completing the current-circuit, while the remaining current would flow into lower latitudes, contributing to the current-circulation in this region.

V—*Asymmetrical characteristics of D_m and of homogeneous auroral arcs*

V. 1—It is of interest to examine whether the asymmetries shown in the magnetic disturbance-field can be associated with asymmetries in the geographical distribution of auroral characteristics. In Figure 7 are compared for various stations the average directions of horizontal vector-components of D_m with the average directions of homogeneous auroral arcs. The horizontal vector-components of D_m are indicated

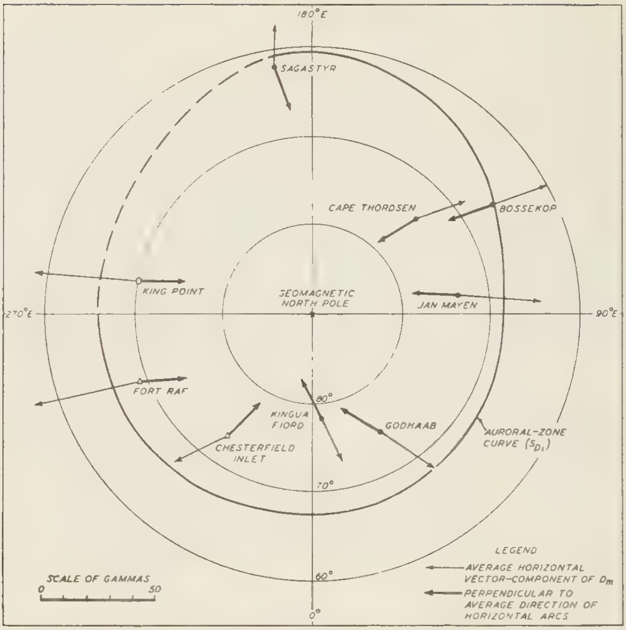

FIG 7—COMPARISON OF AVERAGE DIRECTIONS OF HORIZONTAL COMPONENTS OF D_m WITH PERPENDICULARS TO AURORAL ARCS

● = FIRST INTERNATIONAL POLAR YEAR, 1882-83; △=SECOND INTERNATIONAL POLAR YEAR, 1932-33; □=KING POINT, 1906

to scale by arrows drawn from a point representing the station as origin. Shown also for each station by a heavier arrow is the angular direction 90° plus the average angle between the westward end of auroral arcs and the southward-extending geomagnetic meridian. The auroral data used are those given by Vegard and Krogness [25] for the Polar Year 1882-83 and by Currie [28] for the Polar Year 1932-33 for Chesterfield Inlet.

It will be noted that the auroral arcs have average directions very nearly perpendicular to the horizontal vector-components given by the average daily means D_m of disturbance at all stations. The most noteworthy discrepancies are found at Sagastyr and Chesterfield Inlet. According to Vegard and Krogness the auroral data for Sagastyr may be less reliable than for other stations of the Polar Year 1882-83. At Chesterfield Inlet the auroral data are meaned for photographic observations during the months of January, February, and March, whereas the annual value is used for the horizontal vector-component of D_{mt}, possibly introducing a discrepancy dependent on season of the year. In high geomagnetic latitudes the arcs are more variable in direction and less frequent in occurrence than near the auroral zone.

According to Chapman the observed values of D_m could be due to westward currents flowing approximately upon a spherical surface, concentric with the Earth and in the upper atmosphere. In fact, on a linear-

current hypothesis, the height of the westward current given by the directions of D_{mt} at Tromsö and at Sodankylä near the auroral zone give a height of 290 km, in good agreement with estimates of 300 km for the S_{Dt}-variation. The estimates would be too high because of neglecting induced earth-currents. This suggests that the westward currents responsible for D_m in polar regions flow in ionized regions within the Earth's atmosphere, perhaps near the 100- to 150-km levels where the direct-current conductivity is greater. It thus seems possible that the electric currents causing the disturbance D_m flow at levels in the atmosphere near those for homogeneous auroral arcs. A natural explanation of the fact that the average horizontal vector-component of D_m is nearly perpendicular to the average direction of the homogeneous auroral arcs would then be that these westward electric currents tend to flow along paths provided with greater ionization existing along directions parallel to or along the region occupied by the auroral arcs.

In his studies of the diurnal variation of auroral frequency at high-latitude northern stations, Vegard [16] found this variation appeared to depend on geomagnetic time. The maximum in the auroral frequency of ray-forms occurred within an hour or so of local geomagnetic midnight. This also appears to be the case in the auroral data for south polar regions considered by Hulburt [17], except for stations very close to the south pole. At the latter stations the discrepancies in the time of maxima from local geomagnetic midnight are very large. At stations a considerable distance inside the zone of maximum auroral frequency two maxima may appear in the diurnal variation. At such stations it is also somewhat difficult to establish the times of maxima due to the reduced frequency in the appearance of aurora, necessitating observations over relatively longer epochs of time. Additional data on the diurnal frequency of aurora have been given by Davies [29], Fuller and Bramhall [30], Stagg [24], and by Currie [28], for stations near the auroral zone.

There is need for further careful studies of the diurnal variation of auroral frequency, perhaps separating, as far as possible, the forms with ray-structure from those without ray-structure. The present auroral data all seem compatible with Vegard's suggestion of a rough dependence mainly upon geomagnetic time, if we consider the diurnal variation of auroral frequency only at stations very near the zone of maximum auroral frequency. The maximum in auroral frequency appears a few hours before the morning maximum in magnetic disturbance, the latter appearing on an average at roughly about 3^h local geomagnetic time along the auroral-zone curve for S_{Dt}.

VI—*The contribution of induced earth-currents in the oceans to S_{Dt}*

VI. 1—The data of Figure 3 show that S_{Dt} experiences little variation in amplitude with longitude, the disturbance-field near the auroral zone being zonal-symmetrical in character. Since S_{Dt} is of origin external to the Earth, the variations in the external disturbance-field will induce electric currents in the Earth. The electric conductivity of sea-water is about 4×10^{-11} CGS, but is only about 10^{-15} CGS for surface-rocks. At Fort Rae (inland), Juliannehaab (on the south coast of Greenland), and Bear Island (a small island) the amplitude of S_{Dt} in the three geomagnetic components of force is very nearly the same. It is therefore

highly probable, on grounds of simplicity, that the contribution of induced currents in the oceans to S_{Dt} is small. The induced earth-currents due to the external contribution to S_{Dt} would therefore flow with highest intensity at depths considerably below the Earth's surface, since their contribution may be as much as 30 per cent of the observed field. This finding is in good agreement with the studies of Chapman and Price [31], who neglected the induced currents flowing in the oceans on physical grounds, in the case of the diurnal variation. For variations of short time-period the contribution by induced currents flowing in the oceans may become considerable [31].

For points on the Earth near to and equidistant from the auroral-zone curve for S_{Dt}, there is little variation in the amplitude of S_{Dt}. At the Earth's surface the range with longitude of the vertical component of the Earth's main field may be as great as about 20 per cent, for such points, and greater in the case of the horizontal component. These asymmetries in the field should decrease, more slowly at first, with increasing height above the Earth. At the 100-km level the decrease is likely to be small. For this and other reasons [10] the drift-current and diamagnetic theories of disturbance are difficult to reconcile with the observed amplitudes of S_{Dt}. A dynamo-theory [2, 10, 32], on the other hand, is more flexible and there is some hope that it will afford an explanation of the S_D current-system. It is interesting in this connection to note that S_{Dt} is very nearly symmetrical about the geographic equator, at least in the Western Hemisphere (Fig. 3) and not about the magnetic equator. This suggests a dependence upon the electrical conductivity near the E-region, near a height of 100 km above the Earth, which, averaged for the year, also has a distribution symmetrical with respect to the geographic equator. This is also compatible with the view that the currents flowing in lower latitudes mainly originate near the auroral zone.

In Figure 8 is shown a view of the idealized S_D atmospheric-electric

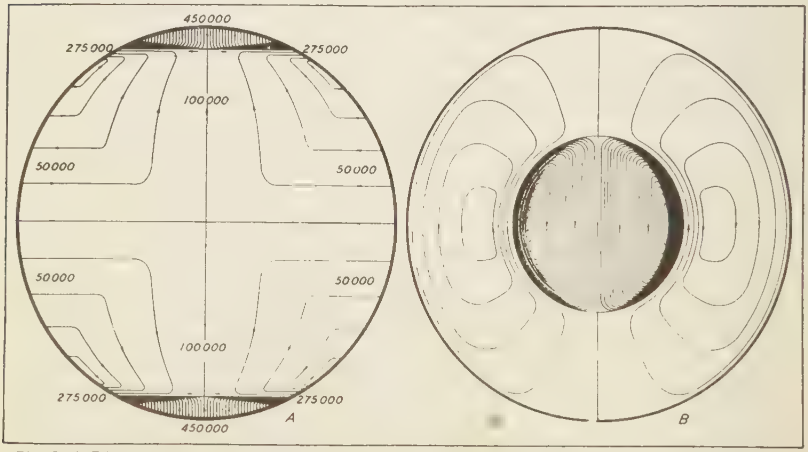

FIG. 8—IDEALIZED CURRENT-SYSTEM IN AMPERES TO PRODUCE ADDITIONAL DIURNAL VARIATION ON MAGNETICALLY DISTURBED DAYS, ASSUMING MAGNETIC AND GEOGRAPHIC AXES COINCIDENT, (A) VIEW FROM EQUATOR AT NOON MERIDIAN, (B) VIEW FROM NORTH POLE (AFTER CHAPMAN)

current-system proposed by Chapman. On the left a view from the Sun is represented. On the right a view from above the north pole is given. The current-system was derived for an ideal Earth having its geomagnetic and geographic axes coincident.

The main systematic features of the extensive data presented above are in good general agreement with a current-system of this form. Certain qualitative changes would improve the agreement with observation in the case of the real Earth. The current-system would be arranged nearly symmetrically about the geomagnetic axis (perhaps more nearly about the axis of the eccentric dipole), except in lower latitudes where the current-flow should be very nearly symmetrical about the geographic equator. The auroral zone would be more closely represented by the auroral-zone curve for S_{Dt} shown in Figure 6. The polar circulation-system would be rotated in a clockwise sense through an angle of about 45° so that the maximum westward current creates a disturbance beneath it at about 3^h local geomagnetic time. The concentration of current near the auroral zone would also be slightly less on the noon-side than on the night-side of the Earth. The lateral distribution of the auroral-zone current would also probably be somewhat greater in the case of the eastward current than in the case of the westward current. Although this current-system is not unique, there is a definite probability that it corresponds with good approximation to the form of the true external electric current-system responsible for the disturbance diurnal variation.

In conclusion, the writer wishes to express his thanks to Dr. J. A. Fleming for his helpful advice and the opportunity of carrying out the foregoing investigation. Grateful acknowledgment is also made of the use of unpublished magnetic data furnished by Dr. D. la Cour, of the Danish Meteorological Institute, and by J. Patterson, Meteorological Service of Canada. The writer is also indebted to various of his colleagues at the Department of Terrestrial Magnetism, particularly Dr. H. G. Booker and A. G. McNish, for helpful discussion of the problem.

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ON THE PRODUCTION OF THE IONOSPHERIC REGIONS *E* AND *F* AND THE LOWER-ALTITUDE IONIZATION CAUSING RADIO FADE-OUTS

By Oliver R. Wulf and Lola S. Deming

Recent observations of the reflection and absorption of radio waves have afforded much information regarding the behavior of the ionosphere during a radio fade-out of the type occurring at the time of conspicuous outbursts in the chromosphere of the Sun. Berkner and Wells [see 1 under "References" at end of paper], using the automatic multifrequency technique, have studied the detailed behavior of the ionized layers during a fade-out and find that conditions in the F_1- and F_2-regions undergo essentially no change. In the *E*-region a small increase in virtual height and maximum ion-density seems to occur. After the *E*-region conditions have returned to normal, abnormal absorption of the exploring radio waves is still observed, showing that absorption occurs below the maximum of the *E*-region ionization. It seems very probable that such radio fade-outs, as suggested by Dellinger [2], are caused by outbursts of ultra-violet solar radiation which produce intense ionization in the atmosphere, and that this ionization occurs principally below 100 km, the radiation experiencing little or no absorption in passing through the *F*- and *E*-regions. There is indication, moreover, that the maximum of this ionization lies in the range 60-80 km.

Intense ionization produced by solar radiation at such an altitude presents an interesting problem. It seems evident that the active radiation must lie in a spectral region where the atmosphere possesses a relatively low absorption-coefficient for these frequencies. With this condition met, the absorption of the effective frequencies producing the ionization might seem, at first thought, to be caused either by one of the normal constituents of the atmosphere or by a new constituent which is not present at greater heights, that is, which is encountered by solar radiation first at these altitudes.

It has been known for some time that air possesses a considerable transparency in the wave-length range 1300-1100Å. Martyn and coworkers [3] have utilized this fact in discussing the origin of such fade-outs. This region of relative transparency is a gap between two intense oxygen absorptions and a region where nitrogen also has no strong absorption. Lyman [4] has discussed this recently and has described a very simple way of demonstrating that some frequencies of radiation lying in this range will penetrate a few cm of air before being absorbed. Price and Collins [5] have shown that oxygen has absorption-bands of considerable intensity in this region, and it seems evident that it is radiation lying between these which possesses the ability to penetrate a few cm of air. Chapman and Price [6] have discussed the absorption of solar radiation by atmospheric gases in general.

The fraction of the atmosphere remaining above 100 km offers a path to incoming radiation which is probably equivalent to a path of air at atmospheric pressure of the order of a centimeter, though this estimate depends of course upon atmospheric constitution and temperature. Above 60 km, however, the equivalent path is much greater, being

more nearly of the order of a meter, and it does not seem probable that radiation in the above-mentioned spectral region will penetrate with appreciable intensity to this height. It is a matter of considerable importance to know the actual height of the maximum of the fade-out ionization and if it proves to be at about 60 km, it would seem rather difficult to account for the ionization by radiation in the region of 1300-1100Å.

The outbursts of ultra-violet solar radiation are not, of course, observed directly, but are believed to accompany conspicuous eruptions on the Sun which show prominently the lines of hydrogen, calcium, and other elements in the visible spectrum. They are observed by means of the spectrohelioscope using these lines, for example, a line of the Balmer series, such as H_α. From the fact that strong hydrogen emission in the visible characterizes these eruptions it seems evident that there is strong emission of the Lyman series. The first line of this series at 1215.7Å lies in the region of atmospheric transparency mentioned above [6, 3] in which solar radiation may be expected to penetrate to altitudes of 100 km or somewhat lower. There may, of course, also be still other such radiations in this spectral region during the outbursts. As mentioned above, however, it appears to the authors that while radiations lying in this spectral range may in part be absorbed somewhat below 100 km, it does not seem probable that they will penetrate with appreciable intensity to 60 km. The state of the existing data on the height of fade-out ionization makes it seem expedient to look for a possible source of ionization due to radiation which can penetrate to such an altitude.

Before attempting to consider the mechanism of the fade-out ionization, it seems necessary to discuss the possible ways in which the E- and F-regions may be accounted for [6*a*], in order to eliminate the processes involved in their production and the radiation absorbed in these processes from consideration of the production of fade-out ionization. It is important at the outset to recognize that the layer-like characteristic of a phenomenon produced in the atmosphere by light absorption does not arise from the character of the law of absorption. It arises rather from the nature of the absorption-coefficient as a function of wave-length. It is true that the absorption of a particular wave-length entering from above into an atmosphere distributed in a gravitational field is decidedly layer-like. But neighboring wave-lengths, carrying the same or even greater total energy, possessing, however, different absorption-coefficients, will be absorbed at other altitudes, and this may result in the almost complete obliteration of any layer-like characteristic [7]. If, however, the curve of the absorption-coefficient as a function of wave-length possesses a portion over which the change with wave-length is small, or, in other words, a relatively flat portion, this will indeed result in the absorption of the energy of many wave-lengths in a localized region in altitude, that is to say, layer-like absorption [8]. The shape of the absorption-coefficient curve possesses thus much significance. Moreover, in the absorption of solar radiation in the atmosphere, values of the absorption-coefficients varying over an extremely wide range (several powers of ten) are important.

So far as absorption by molecular oxygen is concerned, there is reason for expecting that not only the line 1215.7Å but radiation of wave-lengths shorter than the region of transparency mentioned above in-

cluding the entire Lyman series, would penetrate rather deeply, perhaps to the vicinity of 100 km. This is because of the circumstance that at great heights due to the dissociating action of radiation in the daytime, oxygen will exist in the atomic form. Upon coming into the atmosphere from outer space, solar radiation will not encounter oxygen molecules in appreciable amounts until heights are reached at which the pressure is sufficient to give a high rate of association of the atoms to form molecules, this rate finally preventing the dissociating radiation from maintaining an appreciable fraction of this gas in the dissociated state. Chapman [9] has estimated that below 80 km the concentration of oxygen atoms is small compared with oxygen molecules. The more recent measurements of Ladenburg and Van Voorhis [10] of the absorption-coefficients of molecular oxygen in the ultra-violet give values for the coefficients which substantiate this. That is to say, in the daytime as sunlight enters the atmosphere, it finds in the general vicinity of 100 km a rapid increase in the concentration of oxygen molecule which at greater heights has been very small.

In view of the importance of the distribution of molecular oxygen, the authors have attempted a calculation of this dissociating action of solar radiation both with respect to the equilibrium between oxygen molecules and oxygen atoms, and with respect to the rate at which this equilibrium is maintained. In reference 8 an expression (equation 8) was given for the concentration of oxygen atoms as a function of the absorbed radiation and the concentrations of oxygen molecules and total molecules, that is to say, as a function of height. Reasonable estimates were available for the quantities involved in the expression with the exception of the specific rate of the three-body recombination of oxygen atoms which seemed at the time to be uncertain within rather wide limits. Rabinowitch and co-workers [11] have measured the rate of three-body recombination of iodine atoms and of bromine atoms and have also discussed the existing evidence relative to the rate of the three-body recombination of hydrogen atoms and of nitrogen atoms. From these results we believe that a value of k_r for oxygen in equation (8) of reference 8 of 4.2×10^{-32} cc^2/sec (a number used by us in earlier calculations) is sufficiently close to the actual value to make calculations based upon it at least of some significance. This value of k_r has been used in what follows.

On the basis of equation (8) in reference 8, the ratio of the number of oxygen atoms to oxygen molecules per cc has been calculated, utilizing the same oxygen distribution with altitude as in that paper. The total amount of radiation absorbed per cc at each height-interval, designated there as Q_2, is the summation over frequency-intervals of a quantity which is the product of the absorption-coefficient, the number of oxygen molecules per cubic centimeter that exists in the absence of radiation, and the intensity of radiation at this height. This last-mentioned quantity is computed on the basis of the actual intensity of radiation that exists when equilibrium is established, that is, when the number of oxygen molecules normally present at that height and all heights above has been reduced by the dissociating action of radiation. The *S*-shaped curve in Figure 1 shows this ratio so computed using height-intervals of five km, solar radiation being assumed, black-body radiation at 6000°K. The other curves in the Figure illustrate the number of

oxygen molecules per cubic centimeter with altitude in the presence and absence of radiation.

The equilibrium so computed is, of course, of significance only in the regions of altitude where the rate of recombination is sufficiently small that no great change occurs over night in the condition produced by sunlight during the day. In Figure 2 the approximate times of half-dissociation and half-recombination are shown graphically. Above 95-100 km the time of half-recombination has become long compared with one day, the time of half-dissociation being less than one day.

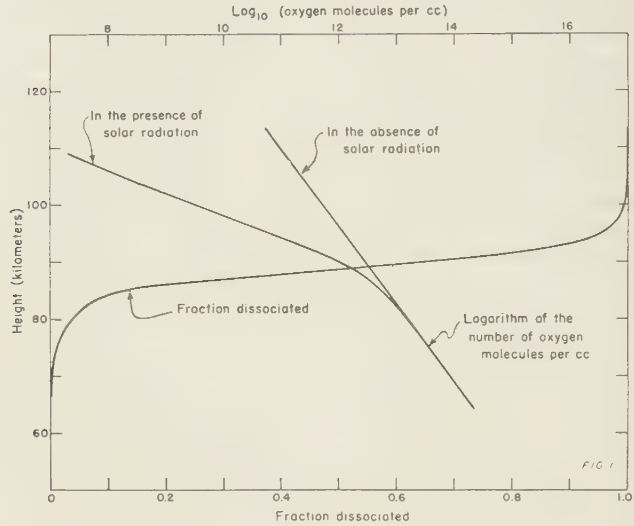

FIG 1

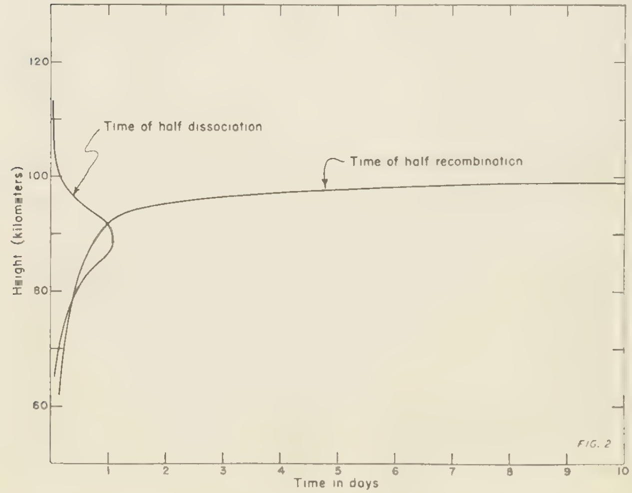

FIG. 2

Above this altitude, therefore, the calculation indicates that the practically complete dissociation of molecular oxygen accomplished by the sunlight during the day will remain appreciably unaltered during the night and that oxygen will exist essentially in the atomic form.

It seems probable that in the atmosphere well above 100 km the principal absorbing constituents, if we except the possibilities of hydrogen and helium, are nitrogen molecule, nitrogen-molecule ion, oxygen atom, and possibly nitrogen atom. Helium, possessing only line-absorption and a very high ionization-potential, does not seem to be a likely source of ionospheric ionization. The uncertainty with regard to the existence of hydrogen in the high atmosphere makes it expedient to attempt an explanation of the observed phenomena without its help. Nitrogen-molecule ion (N_2^+), which undoubtedly exists in the high atmosphere, possesses two known band-systems. If N_2^+ is present in appreciable amounts, one of these, a permitted transition, the 0-0 band of which is at 3900Å, should lead to absorption, and to subsequent fluorescence of these bands where the gas-pressure is very low. We are inclined to believe that such absorption and re-emission is the explanation [7] of Slipher's observation of these N_2^+ bands just before sunrise and after sunset [12]. During the day this faint emission, though undoubtedly present, would not be observable, but it does seem possible that the absorption by N_2^+ responsible for the emission might be observed. It does not seem probable that N_2^+ could itself be the cause of much further ionization because of the relatively high value of its ionization-potential, that is, of the second ionization-potential of the nitrogen-molecule. However, the possibility of as yet unknown dissociational processes accompanying absorption by N_2^+ should not be overlooked.

It seems worth while to attempt to account for the *E*- and *F*-regions making use of nitrogen and oxygen molecules and their products as the absorbing species. Any attempt to describe high-atmosphere ionization by solar radiation raises immediately the question of the absorption of molecular nitrogen in the ultra-violet. No direct quantitative measurements of this exist. The only absorption in the region of wave-lengths longer than 1000Å lies in the vicinity of 1350Å and may be qualitatively estimated as weak from the work of Birge and Hopfield [13] and of Leifson [14]. Transitions in the nitrogen molecule shorter than 1000Å are known, but, so far as the authors are aware, no data exist from which the intensity of these in absorption may be obtained in a direct way. There remains, however, one possible source from which some information regarding the intensity of the ultra-violet absorptions of nitrogen may be obtained indirectly, namely, from the dispersion of nitrogen.

Several investigators have made measurements on the index of refraction of nitrogen at a series of wave-lengths. While engaged in other work one of the present authors noticed that these results gave values for the index of refraction of nitrogen which were consistently higher than the values for oxygen, a rather remarkable circumstance considering the larger number of electrons in oxygen and its intense absorption in the relatively near ultra-violet. The only evident explanation of this seemed to be that nitrogen, which was known to be free of absorption up to the region of the strong oxygen band, absorbed still more strongly than oxygen still farther out in the ultra-violet. The measurements above-

mentioned substantiate this, that is, if used to determine a simple dispersion-expression of one term, they indicate absorption of nitrogen in the far ultra-violet possessing an apparent oscillator-strength appreciably greater than that which one finds for oxygen if the measurements on this latter gas are treated in a similar way.

Index-of-refraction measurements when made only over the range of the visible spectrum are not adequate to distinguish two different effective absorptions in the far ultra-violet, but rather can only give a mean position and mean oscillator-strength for all the effective absorptions taken together. For oxygen, however, there are both extensive measurements on the index of refraction by Ladenburg and Wolfsohn [15] out to 1920Å as well as direct measurements of the absorption-coefficients in the first intense oxygen band by Ladenburg and Van Voorhis [10]. These researches established two intense ultra-violet oxygen absorptions, one (long known qualitatively) whose maximum lies at 1450Å and which was directly measured quantitatively, the other a very broad absorption, the effective center of which appears from the dispersion-measurements to lie at 544A, but which sets in around 1100Å, continues at least as far as 300Å and is presumably a composite of several electronic transitions. The oscillator-strength of 0.20 found for the first of these absorptions in the dispersion-work agreed well with the direct measurements made later upon it as described in reference 10.

For nitrogen, data of Koch [16] indicated two absorptions in the ultra-violet. Koch concluded from his data that the first of these lay at 810Å and that the other lay much farther in the ultra-violet. The *f*-value corresponding to the first of these is 3.27, compared with which we believe that the intensity of the earlier mentioned 1350Å absorption is negligible. It is to be noted that this nitrogen absorption is very intense, the *f*-value being much larger than that for the near ultra-violet oxygen absorption. Presumably one should not lay much stress upon the exact position and area of this absorption as derived from dispersion-data. It is a far reach from the actual measurements out into the far ultra-violet to this absorption, which may indeed itself be composite. But to have the order of magnitude of the absorption-area and its approximate position is of considerable help in gaining an idea of the importance of such absorption in the ionosphere.

Regarding the position of the absorption indicated at 810Å by the dispersion-results, it seems quite possible that this actually occurs at a somewhat higher frequency. According to Chapman and Price the absorption in the region 800-650Å is much more intense than that in the region 1000-800Å, though even in this latter region it is considerable, and it seems probable that the dispersion-measurements would indicate these as one absorption. If so its position would seem to be at somewhat higher frequencies, more nearly at 700Å, for example, rather than at 800Å. The very large *f*-value would then be compatible with the very high absorption indicated by Chapman and Price.

The second absorption indicated by the dispersion-measurements remains to be ascribed to another transition much farther in the ultra-violet and it seems possible that it may correspond to the critical potential observed in electron-impact experiments around 24 volts [17] which pro-

duces the molecular ion in an excited state in which it has more than enough energy to dissociate. At gas pressures which afford sufficient collisions N^+ makes its appearance at this potential, showing that the molecular ion with this energy dissociates upon collision into N and N^+. The minimum energy necessary for this process is 21.8 volts, and it seems possible that the second absorption may represent this process which produces the molecular ion in an excited state unstable with respect to collision. If this is the case the position of the absorption-peak lies in the vicinity of 525Å. We believe from the critical potential-measurements that this transition is presumably a strong one, and for the purpose of making rough calculations to determine the nature of the distribution of the absorption with height, we shall assume an absorption whose breadth is the same as that for the first oxygen absorption and of height some four-fold less than the other nitrogen absorption, this difference being sufficient to give some idea of the difference in height at which two nitrogen absorptions of different absorption-coefficients will occur.

The position in frequency of the maximum of a molecular-absorption process, such as those of interest here, may be estimated by means of the Franck-Condon principle and the potential-energy curves for the two molecular electronic states involved in the absorption-process. The maximum of the absorption will lie to higher frequencies than the frequency corresponding to the lowest energy required to reach the upper state by an amount depending upon the displacement of the upper curve laterally along the axis of the internuclear distance. Where absorption by a cold gas is under consideration one may assume that most of the molecules will be in the lowest vibrational state of the normal electronic state of the molecule, a condition undoubtedly valid for atmospheric oxygen and nitrogen. Under these conditions the most probable transition from the normal (lowest) electronic state to one of the upper states is along the vertical from the minimum of the potential-energy curve for the lowest state.

The potential-energy curves for the normal state of the un-ionized nitrogen and oxygen molecules, and for the normal and an excited state of the ionized molecules are shown diagrammatically in Figure 3, drawn

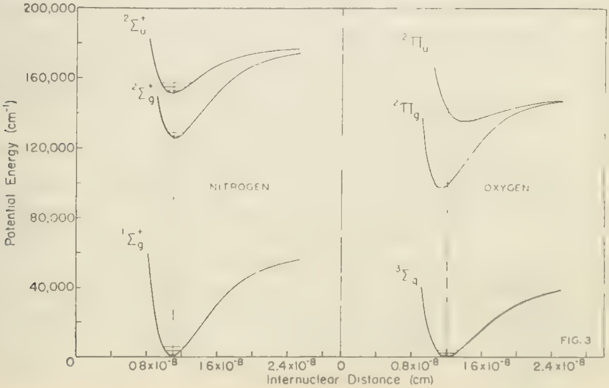

FIG. 3

from data taken from Sponer [18]. For nitrogen this displacement toward higher frequencies of the maximum of the absorption-processes going to the two ionized levels is small, the minima of the upper curves lying almost on the vertical above the minimum for the normal state. The maximum of the intensity of these two ionizing absorptions will, therefore, lie only slightly to higher frequencies than those corresponding to the minimum energies required for the production of these ionized states. For oxygen the effect is somewhat greater especially for the upper of the two states, where the minimum of the curve occurs at an internuclear distance significantly different from that for the curve of the normal state of the un-ionized molecule. The maximum of the absorption corresponding to this transition may be expected to occur at a frequency a few thousand wave-numbers higher than that corresponding to the minimum energy required to produce this ionized state [18*a*].

In computing the number of ionizing quanta absorbed per cc, it is of course necessary to know the intensity of radiation available. For the *E*- and *F*-regions, which are always present in the atmosphere, it would seem reasonable to assume that normal solar radiation is available. This is, of course, a very uncertain quantity, since the farther one goes in the ultra-violet the more apt is the Sun to show deviation from black-body radiation. However, it must be remembered that providing there

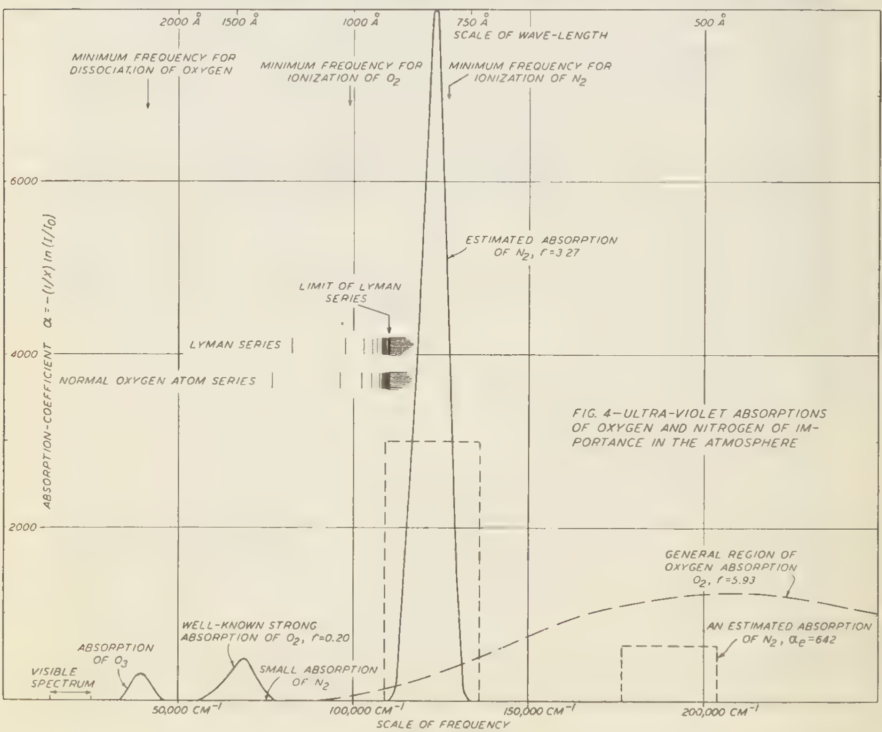

FIG. 4—ULTRA-VIOLET ABSORPTIONS OF OXYGEN AND NITROGEN OF IMPORTANCE IN THE ATMOSPHERE

is a reasonably uniform distribution of solar radiation throughout the ultra-violet, this affects principally the absolute amount of radiation absorbed and not markedly its position in altitude, so that it is probably of importance only in quantitative questions such as the degree of ionization and its rate of maintenance. Since we have no quantitative information concerning the solar intensity in the far ultra-violet, the assumption of black-body radiation at 6000°K affords one basis for making the calculation and will give some idea of the way in which absorption is distributed in height. On this basis, the intensity of radiation available at the frequencies of nitrogen absorptions indicated in Figure 4 which are much higher than those of the 1450Å band of oxygen, will be much less than that in this oxygen region, but the radiation will be absorbed at greater altitudes, where the gas-pressure is much lower and where, therefore, dissociating or ionizing effects may be as important as those produced at lower altitudes by much more intense radiation.

In computing the distribution of the absorption with altitude after the manner of that in reference 8, we have utilized absorption-coefficient curves of rectangular form for the two nitrogen absorptions as shown in Figure 4. For the first of these (810Å) there is also shown absorption of the same shape as the oxygen absorption and of area corresponding to the f-value of this nitrogen absorption. In Figure 4 are also shown the known oxygen and ozone absorptions, the far ultra-violet oxygen absorptions being indicated merely by a dashed line to show approximately the region they cover. (Included in Figure 4 are data relative to the position of the first ionization of molecular oxygen and nitrogen and the positions of the Lyman series of hydrogen and the corresponding series of oxygen atom.) The calculation of the radiation absorbed by nitrogen required, of course, an expression for its distribution in altitude. With the matter of the temperature of the high atmosphere still uncertain, any expression for the distribution of nitrogen is of somewhat questionable value. Up to 100 km it is believed wiser to avoid employing high temperatures. And in spite of uncertainties, it still seems worth while carrying through the calculations on the basis of some model of the atmosphere and solar radiation, since from the calculations some idea may be obtained of what results would be like if they were carried out on another basis]19].

Utilizing the atmosphere which was employed in reference 8, namely, that contained in the paper by Chapman and Milne [19-a] in which diffusion commences at 20 km and the temperature is 219°K throughout, we have computed the distribution of the absorption of radiation by nitrogen in these two ultra-violet absorptions as they are represented in Figure 4. The calculations have been carried out simply for the case of perpendicular incidence, that is, for solar radiation with the Sun at zenith. The distribution of the total quanta absorbed by the nitrogen absorption $f=3.27$ utilizing the absorption-coefficient curve of the shape of the oxygen absorption is shown in Figure 5 and is actually the sum of the absorptions over a series of frequency-intervals, indicated by the smaller curves. The dashed curve represents the total quanta absorbed using the rectangular representation of this same absorption shown in Figure 4 and illustrates that little difference in height results from a considerable change in the shape of the absorption-curve.

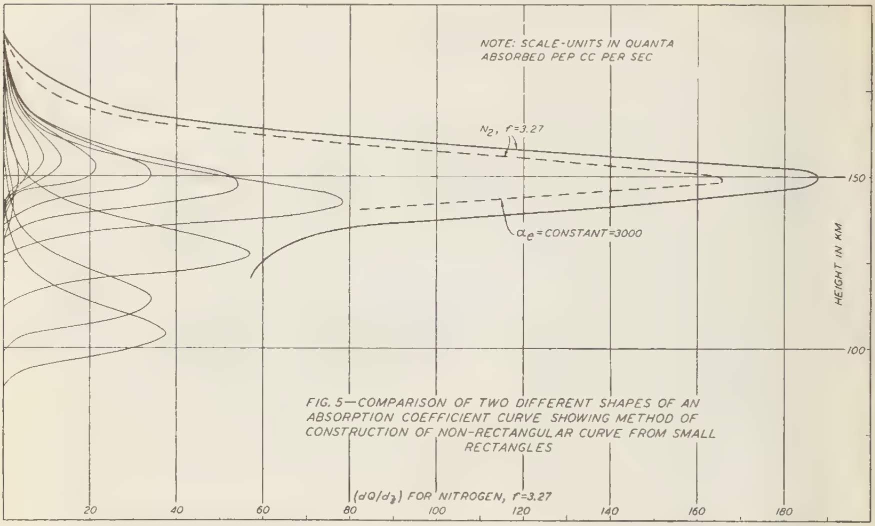

FIG. 5—COMPARISON OF TWO DIFFERENT SHAPES OF AN ABSORPTION COEFFICIENT CURVE SHOWING METHOD OF CONSTRUCTION OF NON-RECTANGULAR CURVE FROM SMALL RECTANGLES

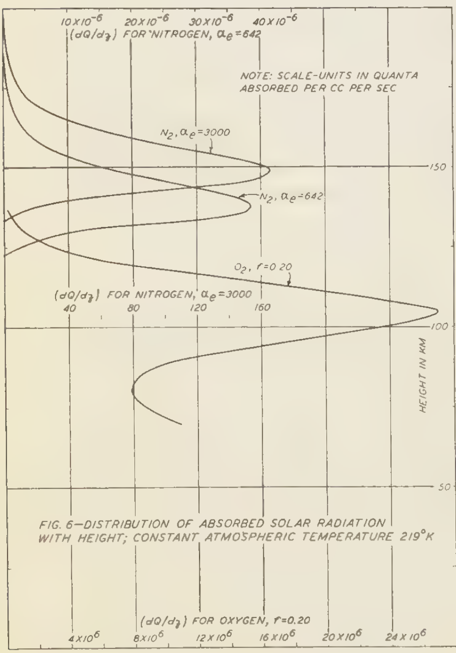

FIG. 6—DISTRIBUTION OF ABSORBED SOLAR RADIATION WITH HEIGHT; CONSTANT ATMOSPHERIC TEMPERATURE 219°K

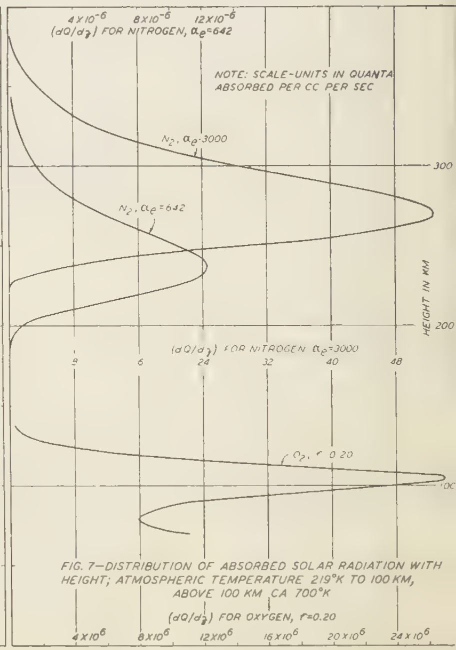

FIG. 7—DISTRIBUTION OF ABSORBED SOLAR RADIATION WITH HEIGHT; ATMOSPHERIC TEMPERATURE 219°K TO 100 KM, ABOVE 100 KM CA 700°K

Figure 6 shows the distribution of absorbed solar radiation with height for both of the strong ultra-violet nitrogen absorptions obtained using the rectangular representation of the absorption-coefficient. The difference in the absorption-coefficient is not sufficient to make a great difference in the height of the two maxima of absorption, a circumstance easily understood in view of the exponential change in the gas-density. On Figure 6 also is shown the absorption of oxygen in the 100-km region, taken from reference 8, and it is evident that this last occurs at approximately the altitude of the E-region. These absorptions are in each case calculated on the basis of the above-mentioned atmosphere without taking account of the disturbance in the distribution of the gases caused by the very absorptions being considered, that is to say, the depletion of the absorbing constituent which produced the absorption, which effect will always tend to force the actual absorption to lower altitudes. However, since the processes tending to restore these absorbing species are of the nature of recombination-processes, the rapid increase of the gas-pressure with decreasing altitude will tend to make it increasingly difficult for the radiation thus to penetrate to lower altitudes.

The two nitrogen maxima come at about 150 km. This is evidently much too low to be reconciled with the experimental determinations of the height of the F-region and since there seems to be no further atmospheric absorption in which these layers originate, unless the second nitrogen absorption is much stronger even than the first—a seemingly very improbable circumstance—this result appears to be evidence that a temperature higher than 219°K exists in the atmosphere above 100 km if the F-region be due to solar radiation.

In order to estimate in a simple manner what temperature is required to place the first nitrogen absorption of Figure 4 at say 270 km, which would be in better agreement with observations on the height of the F-region, we might, for example, utilize the same distribution as before up to 100 km and at this point change abruptly to another temperature, taking the nitrogen above this altitude as gravitationally distributed at this new temperature, based on the number of nitrogen molecules per cc at 100 km. The total nitrogen is increased by such a small amount in this procedure that this seems satisfactory in making an estimate such as this. Calculation shows that the temperature required on this basis is about 700°K. In Figure 7 the distribution of the absorbed quanta as a function of height is shown for the two nitrogen absorptions employing the temperature 720°K above 100 km, the rectangular representation of the absorption-coefficient being used in each case. The oxygen absorption shown is the same as in Figure 6.

The circumstance that there appears to be *two* nitrogen absorptions in the higher atmosphere taken in conjunction with the fact that under certain conditions the F-region splits into a lower (F_1) region and an upper (F_2) region is suggestive. It seems probable from a consideration of the energy-levels of the nitrogen molecule that at least a considerable part of the first of the two absorptions leads to a production of nitrogen molecular ion, N_2^+. The second absorption, lying to shorter wave-lengths, presumably represents the production of an excited molecular ion or the production of one normal and one ionized nitrogen atom. Since in any case the energy of the absorbing species after absorption is much greater than the dissociation-energy of the normal nitrogen molecule, the pro-

duction of atoms may occur in subsequent recombination-processes. Thus the two nitrogen absorptions, occurring at roughly the same altitudes, are assumed to produce at these altitudes nitrogen molecular and atomic ions and nitrogen atoms.

With this survey of the principal absorptions in the high atmosphere an attempt will be made to account for the well-established regions of the ionosphere as well as the abnormal fade-out ionization which seems to occur at relatively low altitudes. Since in the vicinity of 100 km there seems to be pronounced atmospheric absorption only by molecular oxygen, even allowing for some uncertainties in atmospheric distribution and temperature, it seems very probable that the *E*-region must be accounted for somehow on the basis of this. Incoming solar radiation first meets oxygen molecule in this general vicinity, the atomic form having been in preponderance above. The two possible processes which seem to present themselves in the *E*-region are thus ionization of molecular oxygen and ionization of atomic oxygen. As shown in Figure 4 the ionization-potential of molecular oxygen is quite low. The second oxygen absorption has already begun in this vicinity, while the first nitrogen absorption presumably lies to shorter wave-lengths. Although the absorption-coefficient in this oxygen absorption is not known, there can be little doubt that it is adequate to produce intense absorption very soon after molecular oxygen is encountered. As shown in the discussion above, the increase in the concentration of oxygen molecule in the vicinity of 100 km may be expected to be fairly sharp. The ionization of oxygen atoms occurs at somewhat higher energies and comes closer to the first nitrogen absorption. Whether nitrogen shields or not in this instance is questionable. If it does not, then the production of atomic oxygen ions is also a possibility, but it would be expected that this would extend appreciably into higher altitudes, since oxygen atoms are thus distributed. The production of molecular oxygen ion would, as we have seen, be principally confined to a rather narrow region, setting in rapidly at the altitude at which oxygen molecules are first encountered, and practically terminating at only slightly lower altitudes due to the very rapid increase in the concentration of oxygen molecules just in this region. It would seem that this last might well account for the sharpness of the base of the *E*-region. The rather uniform ionization which exists from the *E*-region boundary to the *F*-region may on the other hand be maintained through the ionization of oxygen atom.

A curious circumstance which may be of considerable importance should be pointed out in connection with the oxygen atom. Its ionization-potential by chance practically coincides with the ionization-potential of hydrogen atom. The higher members of the oxygen atom series and their convergence will thus lie in nearly the same respective positions as those of the Lyman series and the two continua will overlap. If the Lyman series constitutes an important part of solar emission in the far ultra-violet, there is thus a favorable chance for the absorption of ionizing radiation in the oxygen atom continuum. At the time of a solar flare this might be of importance, since it seems rather sure that the emission of the Lyman series must constitute an important portion of the total emission of the outburst. However, it is difficult to see how this could be of importance at altitudes much *below* the *E*-region, and hence this

otherwise attractive process probably must be relinquished as an important factor in fade-out ionization. It may, however, be concerned with some small effect in the *E*-region during a fade-out.

In higher altitudes there remain the two nitrogen absorptions, and it is to these that one might look for an explanation of the *F*-region. As shown earlier, a considerable temperature-elevation in the high regions of the atmosphere is necessary to place these absorptions at the observed height. It appears to the authors that if it be granted that these molecular absorptions are responsible for the *F*-region, this constitutes a rather important indication of the temperature in this portion of the high atmosphere.

As suggested above, it seems quite possible that these nitrogen absorptions lead to the production of the molecular ion and of the neutral atom and the atomic ion. It is true that none of the better-known nitrogen absorptions leads efficiently to dissociation of the molecule. But we believe nevertheless that in the very high-atmosphere nitrogen atom must play an important rôle. Whether produced by extremely high ultra-violet frequencies in the process just described or by direct absorption by the nitrogen molecular ion, perhaps through an as yet unknown transition in this species, the rate of the homogeneous three-body recombination at these altitudes will be extraordinarily small, so that even a very weak source of production of nitrogen atoms will be sufficient to maintain a considerable concentration of the atoms.

Absorption by these atoms will, of course, be restricted to the levels at which they exist. The ionization-potential of nitrogen atom is somewhat higher than that of hydrogen or oxygen atom, but absorption in the continuum lying beyond the ionization-potential may be expected here also to produce nitrogen atom ions. Incidentally, it seems that an absorbing species at this height may have rather free access to all frequencies of solar radiation, since above this height presumably no important absorption occurs.

The occurrence of these two absorptions by nitrogen at nearly the same height suggests that the characteristic splitting of the *F*-region into F_1 and F_2 may in some way be dependent on these. We wish here only to point out that, if indeed not only nitrogen molecule ion but also neutral nitrogen atoms are produced as a result of these absorptions, one of these species will show a tendency to migrate rapidly from the position at which it is produced, namely the nitrogen atom. Diffusion-rates are very rapid, and an idea of them may be gained from the table of settling times calculated by Epstein [20]. Since as discussed above neutral nitrogen atom may be a source of ionization through absorption, it seems perhaps plausible that the characteristic behavior of the *F*-region may be connected with the high mobility of this species.

In the above, suggestions have been made as to the origins of the *E*- and *F*-regions of ionization in terms of absorbed solar radiation. In doing this, three, and possibly four or five, of the evident atmospheric absorptions were utilized. Returning now to the problem of fade-out ionization these absorptions are no longer at our disposal. With 0_2^+ and 0^+ so intimately connected with the *E*-region, the production of sudden intense ionization in the region 60-80 km would seem to necessitate a new absorption unless this were to be pictured as a simple deepen-

ing of the *E*-region by a sudden great increase of the intensity of solar radiation—that solar radiation which is responsible for the production of the *E*-region under ordinary circumstances. Berkner and Wells [1] have given evidence that the *E*-region suffers little change during the fade-out. This is evidence against the above point of view, and indicates that the absorption of a component of solar radiation, in high intensity during a solar flare, in the vicinity of 60-80 km accounts for the fade-out ionization.

Searching along these lines for such an absorption, it seems permissible to inquire if there is the possibility of such ion-production by radiation of wave-lengths longer than those utilized in constructing the *E*- and *F*-regions. This appears particularly permissible, because the relative transparency of the atmosphere in the region 1100-1300Å mentioned earlier in this paper seems hardly sufficient to permit radiation to penetrate to such low altitudes, particularly when an increase of temperature in the upper atmosphere has already been indicated (resulting in a raising of the absorbing constituents), and when it is remembered that such fade-outs have been observed about noon. To explain such intense ionization in the very altitudes where it is most difficultly maintained it seems promising to look to a broad absorption and if possible in a region of the spectrum where no question exists concerning the complete transparency of the atmosphere to 60 km. This we believe can only be found in the region of wave-lengths longer than 2000Å.

In the vicinity of 60 km ozone has begun to exist in concentrations which while small are sufficient to absorb some solar radiation in the region 2300-2800Å [21]. Now in the thermal decomposition of ozone in the laboratory, it has been found [22] that ionization is produced by a mechanism not yet understood through the utilization of the energy of this strongly exothermic chemical process. Though not as yet studied in the laboratory, so far as the authors are aware, it seems probable that ionization will be produced more intensely when the decomposition of ozone is brought about photochemically. If the solar flare affords intense radiation in the near ultra-violet region 2300-2800Å, this radiation will be absorbed efficiently by the continuous absorption of the ozone molecule and will probably lead to the production of ionization. We believe that this process may represent the origin of fade-out ionization. It suggests at the same time an interesting laboratory-experiment of importance to ionospheric research, namely the study of the ion-content of ozone which has been irradiated by an intense source of ultra-violet light. Work along this line has been initiated at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington.

The authors wish to express their gratitude to L. V. Berkner and H. G. Booker for their stimulating interest and helpful criticisms, and to thank other members of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington for valuable discussions.

Summary

Ionization responsible for radio fade-outs, now generally believed caused by ultra-violet solar radiation, presents an interesting problem, particularly because of the relatively low altitude at which it occurs. It

appears that the known ionospheric regions E and F may be explained as arising from absorptions of solar radiation by atmospheric oxygen and nitrogen. Intense absorption by molecular oxygen in the relatively near ultra-violet seems to give assurance that molecular oxygen will first be encountered in appreciable amounts by incoming solar radiation in the vicinity of 100 km, the oxygen above this height being maintained in the atomic form by the dissociating action of the absorbed radiation. In the vicinity of 100 km molecular oxygen presumably sets in abruptly and rises rapidly to relatively high densities, leading to a narrow region within which all strong absorption by molecular oxygen, including ionizing absorption, is confined. Dispersion-measurements in nitrogen indicate two absorptions due to this gas in the far ultra-violet, the positions of which are compared with spectroscopic data. These absorptions with two other absorptions due to oxygen and nitrogen atoms produced by the primary molecular absorptions, are utilized in attempting to account for the normal ionosphere. The F-region is attributed to the nitrogen absorptions, and the E-region to the oxygen absorptions. It is concluded that the ionization producing radio fade-outs probably cannot be due to a far ultra-violet radiation because of its remarkably low altitude and its intensity, and that such ionization seems to require the presence of a new constituent, not present at greater heights, which possesses broad absorption in the near ultra-violet. It is considered possible that radiation absorbed by ozone produces this ionization. A laboratory-experiment of some importance in this connection is suggested.

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[19] In giving the amount of radiation absorbed in the Figures which follow, we have made no actual use of this quantity here, the numbers (abscissae) being included merely to indicate the orders of magnitude given on the basis of one model.

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NATURAL RESIDUAL MAGNETISM OF ERUPTIVE ROCKS*

By J. G. Koenigsberger

Part II

§ 1. The apparatus for the measurement of remanence (J_{rn}, J_{rs}, J_{rc}) of magnetization J_K and of susceptibility K of rocks [see sections "Literature," Part I and Part II] are of two kinds:

(*a*) Magnetometers, chiefly astatic [I, 1926*c* and 1927*a*, *b*, etc.], some showing a weak field at the position where the sample is placed, with compensation of the deflection, which requires a regular shape of specimen in measuring remanence or susceptibility [I, 1930*c*]; the sample may be put in a coil with a known magnetic field to measure J_K for different values of H [I, 1930*a*, p. 273].

(*b*) Inductive ballistic devices, which can now be made very sensitive by amplifiers: (1) By pushing the body in one direction through a coil [I, 1925*b*, 1931*c*, 1930*a*, p. 275; II, 1933]; (2) by rotating a body [II, 1937*a*]; (3) by pushing the coil over the specimen which lies in the field of a primary coil [II, 1938]; (4) the isthmus-method [II, 1935]. There are difficulties connected with all these methods, especially when the effect is small and low fields are required.

To measure susceptibility, the balance of P. Curie, or similar devices [I, 1929*a*, 1930*a*, p. 274, 1932*a*, p. 416] requiring fields of over 100 oersteds, but usually over 500 oersteds, have been used; for this method the rocks are pulverized. For low fields, such as that of the Earth, apparatus such as those mentioned under (*a*) can be used [I, 1929*d*, 1930*c*; II, 1937*b*] or an induction balance [I, 1930*a*]. (To obtain orientated samples of rocks, see I, 1890*a*, 1905*a*, 1925*b*, 1930*c*, 1931*d*; II, 1936.) For homogeneously magnetized rocks, the most precise, but not the easiest method, is to determine first the direction m of the maximum residual magnetism and to cut the rock so that a side of the cube would be parallel to m and to heat the sample when m is parallel to the total intensity of the Earth's magnetic field. In most experiments the cube was so orientated that the components of J_{rn} along the sides are approximately parallel to components of the Earth's field of the same relative magnitude and the changes of the maximum component of J_{rn} are measured parallel ($\pm$) to the vertical intensity (0.4 oersted). The total resulting moment of ($J_{rn} \pm J_{rt}$) is observed; the other values can be reduced to it within ± 5 per cent by multiplying by a constant factor. This approximate method is sufficiently accurate since the rocks are more or less non-homogeneous magnetically, anisotropic, and in many cases, as far as they have been examined, the direction of natural magnetization has been changed by movements during cooling.

§ 2. I—Rocks with low average typical constants, with $T_c \leqq 600$°C, with a reversible decrease of J_{rn} or J_{rc} through heating in the opposing field of 0.4 oersted (the decrease beginning upwards from 100°C), with relatively small changes (less than 25 per cent) of the constants on heating, without strong magnetic plasticity (less than 25 per cent). (Pure magnetite or with FeO or $FeO-TiO_2$ in excess.)

*For Part I see Terr. Mag., 43, 119-130 (1938)

When the Curie point of such rocks is between 400°C and 600°C (FeO and $FeO-TiO_2$ in excess less than 10 mass per cent)[1] and when the absence in nature of considerable movements during cooling has been proved (see I, § 7), the rocks can be used for reliable determinations of the direction of the Earth's field at the time of their cooling, and of their geological age.

The method employed for the following specimens has already been described [I, 1930*c*, 1935*g*; see also I, end § 4].

(*a*) *Magnetites with small admixtures* (see Fig. 1)—From I. G. Farben, Griesheim, Germany; Artificial multicrystalline (*Ma*); material often previously heated; Fe_3O_4, slightly anisotropic, probably containing one to two per cent Fe_2O_3 in excess, with $T_c = 600$°C (± 10°). From Traversella, Piemonte, Italy: Unicrystal (*Mt*); brown, transparent; Curie point at first heating at 640°C, where occur changes indicating the presence of larger admixtures, probably of TiO_2; it unmixes after heating for two hours at 650°C and becomes magnetite with probably a few per cent of FeO in excess; Curie point at 540°C (± 15°). Multicrystalline magnetite-ore (*Mg*): From Gellivara, Sweden: Slightly anisotropic, probably containing some Fe_2O_3 and TiO_2 in excess; Curie point at 620°C (± 10°). All measurements are made at 20°C. The powders are a mixture of about five per cent magnetite *Ma* or *Mt* with a Na_2SiO_3-solution $+ SiO_2$, solidified by drying and heating.[2]

Values are determined for thermoremanence J_{rc} acquired on cooling from about 620°C to 20°C in a field $H = 0.4$ oersted, and then on heating to a temperature t in the field of the same (+) or opposite (−) direction, thus giving ($J_{rc} = J_{rt}$), always measured at 20°C. The sequence of the fields during heating is indicated by the numbers in Figure 1. Above

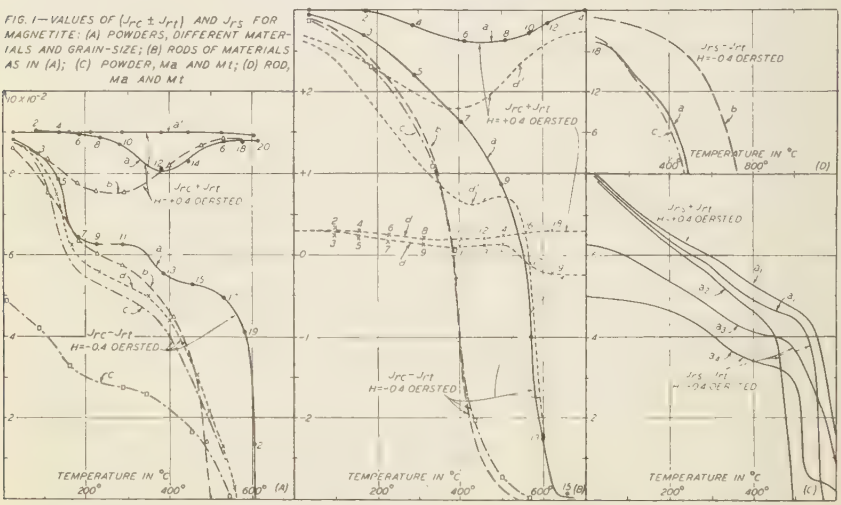


FIG. 1—VALUES OF ($J_{rc} \pm J_{rt}$) AND J_{rs} FOR MAGNETITE: (A) POWDERS, DIFFERENT MATERIALS AND GRAIN-SIZE; (B) RODS OF MATERIALS AS IN (A); (C) POWDER, *Ma* AND *Mt*; (D) ROD, *Ma* AND *Mt*

[1]For $T_C = 400$°C there would be about 41 per cent FeO and 59 per cent Fe_2O_3; thus since Fe_3O_4 ($T_C = 585$°C) = 31 per cent FeO plus 69 per cent Fe_2O_3, there would be an excess of about ten mass per cent.

[2]Mixing with a porcelain clay and then baking may be preferable.

250°C, all these magnetites possess a weak magnetic "plasticity". The curves on heating in one direction, -0.4 oersted (Fig. 1-*A*, *c'*, *d*, and *B*, *b*, *c*), are different from those on heating alternately in ± 0.4 oersted (Fig. 1-*A*, *a*, *b*, and *B*, *a*, *d'*).

(*b*) *Magnetite powders—Ma:* Smallest grain-diameter ≤ 0.06 mm; (*a*) heated alternately in field of ± 0.4 oersted, (*a'*) in a field of $+0.4$ oersted, and (*d*) in a field of -0.4 oersted. Grain-diameter $0.06 < d < 0.015$ mm, from the sample as (*a*); (*c*) always in the field -0.4 oersted; and (*c'*) values for (*c*) multiplied by 1.75 for comparison with (*a*). *Mt:* Grain-diameter $d \leq 0.15$ mm; (*b*) when heated in a field of alternately ± 0.4 oersted as was done with (*a*).

(*c*) *Magnetite rods—Ma* (same specimen as *A*-*a*): $l = 2.04$ cm and $d = 0.066$ cm; (*a*) heated alternately in field of ± 0.4 oersted; (*c*) in field of -0.4 oersted only. *Mt:* $l = 3.10$ cm and $d = 0.19$ cm; (Fig. 1 *B*-*b*) in field of -0.4 oersted only. *Mg:* $l = 2.7$ cm and $d = 0.25$ cm; (Fig. 1 *B*-*d*) alternately in field of ± 0.4 oersted; (*d'*) values for (*d*) multiplied by 10.

(*d*) Values of $(J_{rs} - J_{rt})$ giving the changes of maximal remanence J_{rs} obtained by heating in a field of -0.4 oersted—*Ma:* (a_3) same material as (*A*-*a*); (a_4) material of (*A*-*c*). *Ma* rod: $l = 2.4$ cm, $q = 0.5 \times 0.18$ cm; (a_1) and (a'_1) alternately in field of $+0.4$ oersted and -0.4 oersted, respectively; (a_2) in field of -0.4 oersted only (Fig. 1-*C*).

(*e*) $(J_{rs} - J_{rt})$—*Ma:* Same material as (*B*); (*a*) always in field of -0.4 oersted. *Mt:* Same material as (*B*); (*b*) first heating; (*c*) after three heatings to 350°C, always using -0.4 oersted (Fig. 1-*D*).

The decrease of J_{rs} with temperature occurs when H_c reaches equilibrium with $(H_d \pm H)$ or $f(H_d \pm H)$, f being a constant not yet determined when H is the field applied (here 0.4 oersted). The decrease is instantaneous. For isometric grains of magnetite, H_d is of the order of $(J_{rs}:K)$, where K for small grains does not differ greatly from K_0 (see I, § 6-*b*), and up to 400°C for magnetite with $T_c = 585$°C is of the same order as at 20°C, while H_c decreases rapidly with t. An outer field H of 0.4 oersted is therefore small as compared with H_d and has little effect up to about 400°-500°C.

For purposes of comparison with rocks, the curves of Figure 1-*A* for powders of small grain-size in the case of J_{rc} must also be measured in fields which change their direction after each observation, as is done for rocks, whether for approximately isometric multicrystalline grains, subdivided as *Ma*, or for unicrystalline grains like *Mt*. Some elongated multicrystalline grains with a small demagnetizing force H_d may behave like *B*-*d'* or *B*-*a*. The curves *B*-*a* or *B*-*d* for $(J_{rc} \pm J_{rt})$ have no secondary maxima at 200°C and 450° to 500°C; the latter are therefore due to the unequal change of H_c relative to K_0 by temperature (see I, 1933*g*, Figs. 1, 3, 5). Other details of the curves, especially the fact that a decrease begins at low temperatures and goes on continuously, can be explained on the basis of grains of different size and form randomly distributed throughout the body. This gives rise to different values of H_c and H_d, although only average values are measured. There is one value of H_d for a rod of artificial magnetite but many values of H_c associated with the small crystals comprising the rod. The same is true for the rod of heated and cracked Traversella magnetite (*B*-*c*). But the rod of the fresh Traversella unicrystal (*D*-*c*) is somewhat homogeneous with a somewhat uniform value of H_c when heated for the first time and when

also prepared with great care. The curve *D-c* approaches most closely the form of the ideal curve, which would probably consist of a horizontal and a vertical line, approximately given by observation in the case of hematite. The changes in slope of the curves for $(J_{rc}+J_{rt})$ in *A-a*, *B-a*, and *B-d′* are due to a magnetic plasticity, or more accurately speaking, to a temperature-hysteresis effect, the direction of the field applied during heating to a higher temperature giving an impressed remanence which cannot be annulled by a field of equal magnitude in the opposite direction. The effect may perhaps be caused by a kind of crystallization-remanence (I, § 5) due to a reversible mixing and unmixing of small quantities of Fe_2O_3 [class III]. But the Traversella magnetite probably without Fe_2O_3 in excess (with T_c below 585°C after heating) shows the same effect. Therefore it may be that only very slight, perhaps continuous changes in the space-lattice are going on as the Curie point is approached, and give rise to a small crystallization-remanence. A time-lag of this effect could not be observed. However, no detailed study was made. Other observations not given here seem to indicate that for the time-lag of normal magnetite the time of heating (one to two hours) was perhaps short for $t<300$°C and long for $t>450$°C. Heating the sample, using the same direction of the field —0.4 oersted, gives curves different from those obtained with alternate reversals of the field (compare Fig. 1, *A-a*, with *A-a′*, *A-c′*, *A-d*, and compare *B-a* with *B-b*); this is also due to the same magnetic plasticity which is marked in artificial magnetite ($T_c=$ 585° to 610°C) above 200°C, and is in Traversella unicrystals ($T_c=$ 540° to 580°C), also observable above 100°C. The lowering of J_{rs} occurs because of a greater decrease of H_c than of K with temperature—the small outer field having small influence—hence no great difference exists between graphs $C\text{-}a_1$ and $C\text{-}a'_1$ of Figure 1 for $(J_{rs}+J_{rt})$ and $(J_{rs}-J_{rt})$, respectively.

This is also true for all rocks measured belonging to Classes I and II. The possible presence of a plasticity is masked in the observation for J_{rs} by this large decrease. A very small portion of the decrease of J_{rs} may be a time-effect depending on temperature. This effect is greater the longer the sample is heated; however, heating over a period of four hours results in only a very small difference as compared with two hours, the time usually employed for heating and cooling. The decrease of J_{rs} by heating for powders (Fig. 1, $C\text{-}a_3$ and $C\text{-}a_4$) is slower than for rods (Fig. 1, $C\text{-}a_1$, and *D-c*), the initial apparent values of J_{rs} being much smaller for powders than for slender rods with greatly diminished H_d; the curves for powders show the changes of slope (inflections) relatively much less pronounced than for J_{rc}.

The following data will illustrate some of the criteria of Part I. For samples of about one-mm diameter and 2-cm length, for H less than 5 oersteds, the true value of K_0 was equal to 6 for the unicrystal of Traversella (*Mt*); for artificial multicrystalline magnetite (*Ma*) it was 1.35; for multicrystalline fine-grained material of Gallivara (*Mg*) it was 1.20. The true values of H_c found were as follows: *Mt*, 5; *Ma*, 14.6; *Mg*, 18. The apparent values for grains as measured in rocks depend on form and size of grain (see § *C*). For the two rods (*B-a* and *B-b*), with little or no H_d, J_{rc}, and J_{rs} are highest and approximately equal to their true values: For *Ma*, $J_{rc}=3.0$ and $J_{rs}=19$. For a unicrystal of *Mt* that has been heated and hence has a space-lattice slightly disturbed by unmixing (see above),

$J_{rc}=3.0$ and $J_{rs}=20$; before the first heating $J_{rs}=24$. For a rod of *Mg* (see Fig. 1, *B-d*) of diameter small relative to the length and hence having a large value of H_d, $J_{rc}=0.65$. Powders with rather large grain-diameter of multicrystalline *Ma* (see Fig. 1, *A-c*), give $J_{rc}=5.0\times10^{-2}$, $J_{rs}=5.0$; with smaller grain-diameter (see *A-a*) $J_{rc}=8.9\times10^{-2}$; $J_{rs}=6.2$. For *Mt*, $J_{rc}=8.7\times10^{-2}$, all directly observed and hence apparent values.

The characteristic constants (see I, § 8) of apparent values of the magnetites of Class I are: For medium size $0.005>d>0.1$ mm and with FeO and ($FeO—TiO_2$)<10 per cent in excess, $0.20<K_0<0.05$ (for approximately pure magnetite grains (*pm*), $K_0=0.2$); $10>Q_t>1.0$ (*pm*, 1 to 1.5); $75>R>30$ (*pm* 40 to 50); $100>S>30$ (*pm* 50 to 90); $200>H_c>30$ (*pm*, H_c 110 to 140); 600°C$>T_c>$200°C (*pm*, T_c 570° to 595°C). Permanent changes $\triangle K$ of K by heating reach limits up to ±15 per cent; $\triangle H_c=-10$ per cent to $+20$ per cent; 20 per cent $>\triangle R>-30$ per cent; $\triangle J_{rs}$ to $+25$ per cent. For pure magnetite all permanent changes are very small or, when preserved from oxidizing by heating, equal to zero.

(*f*) *Effusive rocks*—Basalts (see Fig. 2): (I) From Münsterberg, Prussia, Germany; geological age, young tertiary or quarternary, $s=3.45$; volume-percentage[3] (vpc) of pyrrhotite 1.6, of magnetite 3.8. (II) From

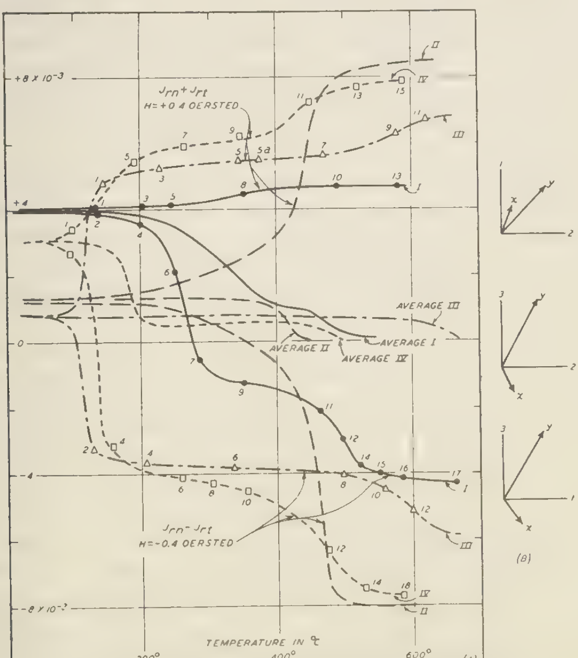


FIG. 2—VALUES OF ($J_{rn}\pm J_{rt}$) FOR YOUNG TERTIARY OR RECENT BASALTS (A) SPECIMENS I, II, III, AND IV; (B) DIRECTIONS OF J_{rn}, BELOW 350°C = x AND ABOVE = y IN THE THREE PLANES OF CUBE AS INDICATED AT RIGHT

[3]Volume-percentage is denoted vpc and mass-percentage mpc. For the estimation of ferromagnetic materials given by D. Hoenes, see I, 1935g, p. 207.

near Kassel, Prussia; same age as I. (III) From Biltstein, Fulda, Prussia; same age as I; $s=3.30$. (IV) From Hornberg near Kassel, Prussia; same age as I; $s=3.30$; 8 per cent by volume of magnetite of diameter 5-10μ. Values of J_{rn}—I, 4.4×10^{-3}; II, 1.3×10^{-3}; III, 1.1×10^{-3}; IV, 3.4×10^{-3}. Values of $K_0(f)$[4]—I, 2.8×10^{-3}; II, 5.2×10^{-3}; III, 2.2×10^{-3}; IV, 4.4×10^{-3}. Values of Q_n—I, 3.5; II, 0.55; III, 1.0; IV, 1.7. Values of $K_0(h)$—I, 3.0×10^{-3}; II, 4.7×10^{-3}; III, 1.9×10^{-3}; IV, 4.3×10^{-3}. Values of J_{rc}—I, 4.8×10^{-3}; II, 8.1×10^{-3}; III, 6.7×10^{-3}; IV, 7.8×10^{-3}. Values of Q_t—I, 1.8; II, 3.9; III, 8.0; IV, 3.9. Values of Q_{nt}—I, 0.97; II, 0.16; III, 0.16; IV, 0.43. Values of $J_{rs}(h)$—I, 2.4×10^{-1}; II, 3.7×10^{-1}; III, 3.2×10^{-1}; IV, 1.4×10^{-1}. Values of $R(h)$—I, 80; II, 78; III, 170; IV, 32. Values of S—I, 56; II, 46; III, 48; IV, 18. Values of $H_c(h)$—I, 175; II, 110; III, . . . ; IV, 90. Values of $J_{rs}(f)$—I, 1.8×10^{-1}; II, 2.8×10^{-1}; III, 3.0×10^{-1}; IV, 1.25×10^{-1}. Values of $H_c(f)$—I, 150; II, 85; III, . . . ; IV, 45. Values of $R(f)$—I, 64; II, 54; III, 140; IV, 28. Values of Curie point (magnetite with lower Curie point is designated x and with higher Curie point y) for x—I, 275° to 300°C, vpc 60; II, 300°C, vpc 15; III, 170°C, vpc 75; IV, 170°C, vpc 60. Curie point of y—I, 580° to 620°C, vpc 40; II, 450°C, vpc 85; III, 600°C (?), vpc 25; IV, 550°C, vpc 40.

Probable ferromagnetic materials—I, 30 vpc pyrrhotite and 30 vpc (x) magnetite (with an excess of 15 mpc FeO and 10 mpc (?) TiO_2 in excess) and 40 vpc (y) magnetite with some 10 mpc TiO_2. II, 15 vpc magnetite (with 15 mpc FeO in excess and 5 mpc (?) TiO_2) and 85 vpc magnetite with 5 (?) mpc FeO and 5 mpc (?) TiO_2. III, 75 vpc magnetite with 30 mpc FeO and 10 mpc TiO_2 in excess; 25 vpc magnetite with 10 mpc (?) TiO_2. IV, 60 mpc magnetite with 35 mpc FeO in excess and 5 mpc (?) TiO_2 and 40 vpc with 5 vpc FeO and 5 mpc (?) TiO_2.

The apparent value of K_0, computed with the aid of Ollendorff's formulae [I, 1931*a*, 1934*b*, p. 387], for the pyrrhotite of I is 0.04, and for the magnetite of I is 0.12, while the apparent value of K_0 for pure isometric magnetite of diameter $>50\mu$ is about 0.23. For the magnetite of IV, K_0 is only 0.06, the low values being due partially to the small grain-size and partially to the large excess of FeO, the latter depressing T_c and thus also lowering the value of K.

The Curie point of magnetite in the rocks, as given above, was computed in the following manner. As the temperature during heating approaches the Curie point, J_{rc} decreases rapidly (for example, Fig. 1, curve *A-a* from 17 downwards), in a field of -0.4 oersted, until the final value of $-J_{rc}$ is reached at 15° to 5°C below T_c. The whole continuous decrease (for example, Fig. 1, curves *B-d′* and *B-a* from 300° to 600°C) is about 1.5 to 1.8 times J_{rc}. The characteristic constants are chiefly averages given by mixtures of the two or more magnetites or ferromagnetic substances present in the rock. The average does not generally follow the simple law of addition of volume-percentages, extreme values having lesser influence. Therefore the values given above for percentages are only very approximate. However, these values are only of secondary importance in the major problem of determining the Earth's magnetic field for past epochs and the age of rocks. Observations on three to five cubes from different localities for confirmations of movements or their absence would have much more geophysical importance than an accurate

[4] f = fresh virgin rock; h = heated, chiefly to 600°C, sometimes to 700°C.

magnetic analysis at different temperatures using the differences of the Curie points.

H_c is lowered by FeO and probably increased by TiO_2; but as at times only the apparent value of H_c of the rocks, that is, of the magnetite grains, can be measured, an elongated shape of grain in a given direction can diminish H_c in that direction. Decrease of grain-size diminishes the true value of K and increases the true value of H_c (see I § 5). Therefore the influence of TiO_2, or whatever other admixture which may increase the characteristic constants, cannot be separated from the effect of grain-size. In most deductions noting the presence of high characteristic constants is of greater importance than their cause.

The permanent changes of K produced by heating these basalts, sometimes an increase and sometimes a decrease, are small (<25 per cent). These rocks are, therefore, in the first approximation suitable for determination of age. Q_t lies between 4 and 8, R between 30 and 80, H_c between 90 and 175—as is to be expected for magnetite of normal grain-size, $d \geqq 30\mu$. Basalt III has higher values of Q_t and R (H_c was not measured) which are probably not due to the small size of grain of magnetite of $T_c=170°C$, but to the 25 per cent of magnetite of $T_c=600°C$ containing much TiO_2.

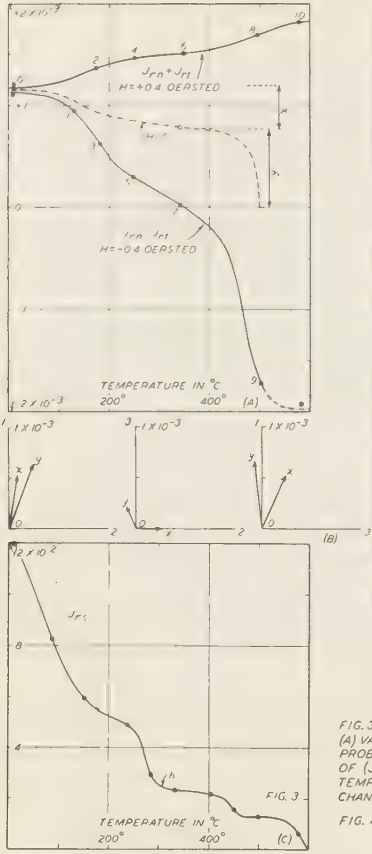
For basalt I, the constant characteristic for age Q_{nt} is >0.85, as is to be expected for young rocks with $T_c>250°C$. Q_{nt} for basalt IV is only 0.43 because of the very low T_c of the x-portion of the magnetites and of movements observed[5] in the cube. Basalt III has relatively high Q_n but low Q_{nt}, because of the great content of magnetite of low T_c ($x=75$ per cent) and because this basalt is perhaps of greater (old tertiary?) age. Basalt II, which corresponds to magnetite of normal T_c and H_c, has low Q_{nt} which can be explained only by movements during cooling but this was not measured. The three ways of detecting movements were mentioned in I, § 7.

(g) *Intrusive rocks* (Fig. 3) -(1) Granodiorite: From St. Eulalia, Andes, Peru, probably cretaceous, collected by Professor A. Buxtorf of Basel, Switzerland. Values are: $J_{rn}=1.15\times10^{-3}$ (resultant for the three directions); $K_0(f)=4.2\times10^{-3}$; $Q_n=0.63$; $K_0(h)=3.5\times10^{-3}$; $J_{rc}=1.9\times10^{-3}$; $Q(t)=1.0$; $Q_{nt}=0.63$; $J_{rs}(h)=0.77\times10^{-1}$; $R(h)=22$; $S=40$; $T_c=520°C$; $H_c(h)=155$. Values for new cube: $J_{rs}(f)=1.20\times10^{-1}$; $R(f)=31$; $H_c(f)=130$; $H_c(h)=160$. The curve (Fig. 3, A) for $(J_{rn}-J_{rt})$ has approximately the same shape as for the powder of Traversella magnetite (Fig. 1, A-b) and the relatively small values of H_c, Q_t, R, and T_c, are such as are expected for magnetite with some excess of FeO. Q_{nt} has a value as is to be expected for such approximately normal magnetite in mesozoic rock.

The curve C (Fig. 3) for J_{rs}, after the first heating of the cube, is similar to that of powdered multicrystalline artificial magnetite (Fig. 1, C-a_3 and C-a_4). Such a combination of larger and smaller grains would give rise to a curve of this form, some of the magnetite crystals probably being cracked[6] by the first heating. Other changes produced by heating

[5]Figure 2-B shows how movements during cooling have been detected for a cube of side four cm. The direction m of total magnetization is different for magnetite with lower Curie point (x) than for higher Curie point (y); this is shown by measuring the three components parallel to the sides 1, 2, 3 of the cube and representing their resultants for x and y in the three planes (1, 2), (2, 3), (3, 1). These resultants should of course have the same directions in the absence of movements.

[6]For heating to $t°$, about one-half hour is required. The minerals in rocks often have small admixtures of other minerals and of water and gases; they crystallize under pressures of 100 atmospheres and more and crack therefore by heating at one atmosphere.



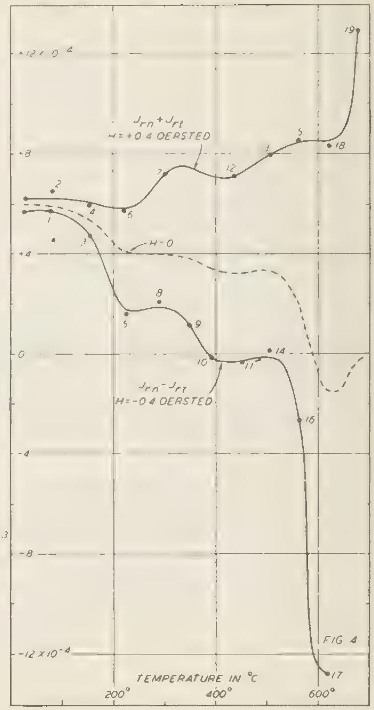


FIG. 3—VALUES OF $(J_{rn} \pm J_{rt})$ AND J_{rs} FOR GRANODIORITE (A) VALUES OF $(J_{rn} \pm J_{rt})$ PARALLEL TO SIDE 1 OF CUBE—PROBABLE VALUES FOR H=0 SHOWN DOTTED; (B) VALUES OF $(J_{rn} \pm J_{rt})$ PARALLEL TO SIDES 1, 2, AND 3 OF CUBES AT TEMPERATURES CORRESPONDING TO x AND y OF (A), (C) CHANGE OF J_{rs} WITH INCREASING TEMPERATURE

FIG. 4—VALUES OF $(J_{rn} \pm J_{rt})$ OF ANDESITE

are the increase of H_c and decrease of K, as one would expect if the size of grain is diminished by cracking during heating (see I, § 5). The relative maximum at 200°C, 350°C, and 500°C are clearly evident in the J_{rs}-curve of heated rocks and indicate the presence of grains of small size almost immediately after heating.

The directions for x and y (see A, Fig. 3) in B show small but significant differences. Only in 2 and 3 is the resulting moment so small that the difference of direction is without meaning, as may be seen if the resultant of the three components is considered. The movements between 350°C and 520°C were therefore slight.

(h) Andesite (Fig. 4): From lower part of Crested Butte, West Elk Mountains County, U.S.A., post-cretaceous. Values are: $J_{rn}=6\times10^{-4}$ (resultant value for the three directions); $K_0(f)=1.8\times10^{-3}$; $Q_n=0.70$; $K_0(h)=1.6\times10^{-3}$; $J_{rt}=1.3\times10^{-3}$; $Q_t=1.6$; $Q_{nt}=0.46$; $J_{rs}(h)=1.20\times10^{-1}$; $R(h)=75$; $S=90$; $H_c(h)=200$; $T_c=610$°C; new cube: $J_{rs}(f)=1.30\times10^{-1}$; $R(f)=72$; $H_c(f)=160$; $H_c(h)=190$; $J_{rs}(h)=1.30\times10^{-1}$.

The curve for $(J_{rn} \pm J_{rt})$ of Figure 4 has approximately the same shape as that for the finer grains of artificial (multicrystalline) magnetite (Fig. 1, *A-a*), with the first relative maximum at 200° to 300°C and a second relative maximum at 400° to 500°C. The characteristic constants H_c, Q_t, R, S, T_c, are somewhat higher than for normal magnetite with medium grain-size. Considering the apparent plasticity, which is here permanent and therefore rather a small crystallization-remanence (compare class III-*a*), as shown by the shape of the curve for $(J_{rn} \pm J_{rt})$ above 400°C, some small admixture of Fe_2O_3 is probable (compare class III). The value $T_c = 610°C$ indicates furthermore the presence of TiO_2, which likewise accounts for the values of H_c, R, S, Q_t higher than for normal magnetite. The value of Q_{nt} is not as high as might be expected for a post-cretaceous rock; tests for internal movement were not made. Movements on a larger scale in the laccolithic sheet can be studied only in the field.

(*i*) *Age of rocks and value of* Q_{nt}—For some rocks of class I of approximately known geological age see Figure 5 and Table 1 for values of Q_{nt}. Formerly the curves for $(J_{rn} \pm J_{rt})$ were not measured in the manner now employed but the characteristic constants, T_c, and the changes due to heating to two or three temperatures were observed. Thus it is possible to single out approximately the rocks of class I of a more or less accurately known geological age. The Q_{nt}-values were plotted on a diagram with time as abscissa. The time-limits of the geological periods can now be

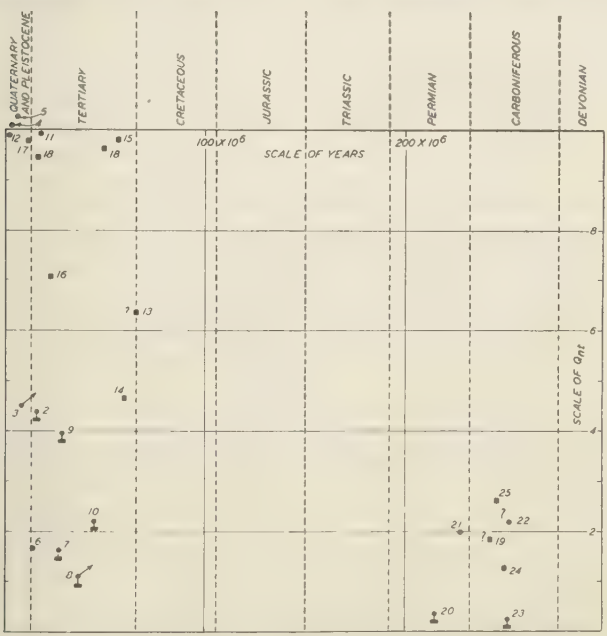


FIG. 5—VARIATIONS OF Q_{nt} WITH GEOLOGICAL AGE OF ROCKS
[•=EFFUSIVE ROCKS AND DYKES; ▪=INTRUSIVE ROCKS; ⊥=T_c < 250° FOR THE MAJORITY OF MAGNETITES; ↗=MOVEMENTS OBSERVED; ?=AGE UNCERTAIN]

determined with sufficient accuracy by radioactive methods [see Report of Committee on the Measurement of Geologic Time, by A. C. Lane, with chart I, by W. D. Urry, February 2, 1936]. (In Figure 5, for example, the exact relative position of the sequence of the basalts in the tertiary is arbitrary; the age is rarely known accurately.) Where movements at temperatures under 585°C have been observed in a rock, these are indicated in the Figure; such observations, however, were made only casually and not systematically, as should have been done for more than one specimen for each locality. The possibility of the existence of such movements consolidating effusive rocks at such relatively low temperatures and their frequencies of occurrence were not known when these investigations were begun.

TABLE 1—*Identification of rock-specimens as numbered 1 to 23 in Figure 5*

Basalts	Granodiorite
(1) Münsterberg, Germany	(13) Andes, Peru
(2) Hornberg, Germany	
(3) Eifel, Germany (porous)	Granite
(4) Eifel, Germany (porous)	(16) Loch Kilchrist, Syke, Great Britain
(5) Eifel, Germany (massive)	(17) Bergwell, Switzerland
(6) Kassel, Germany	(18) Monte Capanna, Elba, Italy
(7) Biltstein, Germany	(19) Baveno, Italy
(8) Oberramstadt, Germany	(24) Brohna, Germany
(9) Frankenstein, Germany	(25) Hartz, Germany
(10) Goldberg, Germany	
(11) Niederobfleiden, Fulda, Germany	Porphyrite
Andesites	(20) Bunzlau, Germany
(12) Pico da Orizaba, Mexico	
(14) Crested Butte, West Elk Mountains, United States	Amphribolaplite
	(21) Duchroth, Pfalz, Germany
(15) Kate's Mill, West Elk Mountains United States	
	Diabases
	(22) Neubrohna, Germany
	(23) Bautzen, Germany

§ 2. (II)—In addition to the rocks discussed in I of § 2 there are rocks with high average typical constants ($R>200$, $H_c>250$ oersteds, $Q>10$), generally with $T_c \geqq 580°C$; with little or no decrease of J_{rc} or J_{rn} by heating up to 300°C or more in field of -0.4 oersted; with changes, through heating, of the typical constants from 10 to 50 per cent, and without strong magnetic plasticity. (Magnetite with much TiO_2-FeO and little $TiO_2-Fe_2O_3$[7] in excess, up to about five per cent for the latter.)

[7]There is probably one type *A* in which normal magnetite $Fe_3O_4 = 2FeO + FeO_2$, where Ti replaces Fe in FeO (or perhaps also TiO_2 replaces FeO which would change the oxygen-content, a question not as yet studied analytically) and a type *B*, where Ti replaces Fe in FeO_2 in the space-lattice. Of course no such special groups like FeO ar FeO_2 are in the lattice, but an indication is given of the points where Ti can replace Fe. The second type, titanoiozite, is, it seems to me, that studied by Chevallier and Pierre (I. 1932*a*), giving T_c according to the actual value $FeO:Fe_2O_3$ on the straight line of Kopp but augmented by about 3° to 5°C for each per cent of TiO_2. The magnetites *B* have a density less than for normal magnetite, are somewhat stable, and unmix slowly by heating perhaps through oxidation; they are the principal constituents of the so-called titanomaghemites and of the magnetites of rocks of class II. The type *A*, titanomaghemites, is here that of the magnetites of rocks of class III, unmixing immediately by heating at atmospheric pressure, behaving like magnetite having Fe_2O_3 more than one per cent in excess, giving unmixing in a magnetite field crystallization-remanence, having a cell-edge of maghemite perhaps a little larger with much Ti; they are the minor constituents in so-called titanomaghemite or titanomagnetite. In rhombohedral ilmenite $FeTiO_3 = FeO + TiO_2$, Fe can replace some Ti without fundamental changes of symmetry in the space-lattice. This type is well studied; the magnetites with TiO_2 are not. The foregoing discussion is only for the purpose of emphasizing the differences between magnetites with Ti, essential for the problem here considered.

These rocks may be used for the reliable determination of the direction of the Earth's field in cases where no very large movements have been observed, but they are generally not suitable for reliable determination of age, since the decrease of remanence with time is very slow[8] for magnetite with high values of H_c and T_c.

(1) *Titanomaghemite* (Fig. 6)—Magnetite of Buon Accord, Pretoria, Union of South Africa (kindly supplied by Prof. H. Schneiderhöhn, Freiburg in Bayem, Germany) appears to be a magnetite where Fe is partly replaced by Ti[7]. This mineral is somewhat unstable when heated but not to such an extent as pure maghemite (Fe_2O_3 in a space-lattice like magnetite). The magnetites of the following rocks of class II have a still less amount of titanomaghemite-magnetites. The ferromagnetic substances of class III resemble unstable maghemite much more closely, the changes by heating being completely irreversible

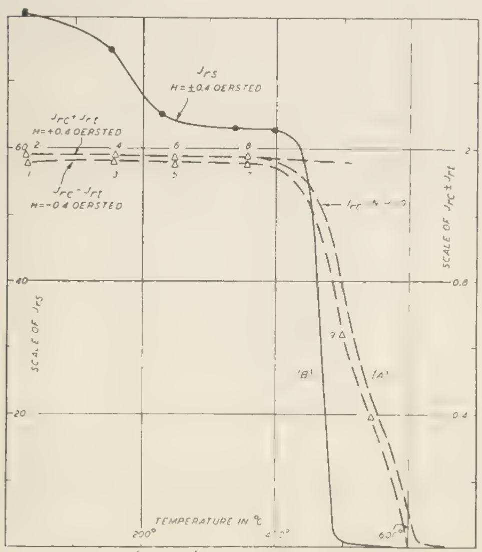


FIG. 6—VALUES OF ($J_{rc} \pm J_{rt}$) AND OF J_{rs} FOR TITANOMAGNETITE-MAGHEMITE

In Figure 6, *A* is a curve for ($J_{rc} \pm J_{rt}$) after two heatings to 700°C; the horizontal line up to 400°C followed by a decrease to the Curie point at about 620°C is characteristic; $J_{rc} = 1.18$. Curve *B* shows change of J_{rs} on heating. The first decrease observed from 150°C to 220°C in J_{rs} is probably due to an admixture of normal magnetite, which gives a much larger effect in J_{rs} than in J_{rt} than in the case of titanomagnetite, because for grains the latter has a much lower K and a higher H_c and therefore a high J_{rc} (I, § 5). After longer heating the so-called titanomaghemites give principally magnetite (not hematite) and are therefore

[8]The dykes of pre-Karoo age in the Union of South Africa (H. Gelletich), like the older (precarboniferous?) titanomagnetite of Buon Accord, Pretoria, have retained a very strong remanence directed opposite to the Earth's field.

better called titanomagnetite. Before heating $J_{rs}=80$ and $H_c=380$. The sample was in the form of an ellipsoid of dimensions: $2a=2.0$ cm; $2b=2c=0.35$ cm; $v=0.120$ cc; $S=4.65$ for which $K_0(f)=6\times10^{-2}$ and $J_{rn}=165$. For powder with isometric grains with $d=0.05$, $K_0(f)=$ 3 to 4×10^{-2}, $K_0(h)=1$ to 2×10^{-2}, $J_{rs}=80$ to 110, $H_c=450$ to 570, $J_{rc}=0.8$ to 1.1, $R=1700$, $Q_t=50$, $S=100$, $T_c=620°$C.

(2) *Hyperite* (Fig. 7)—From Ölme, Värmland, Sweden, archaic, furnished by the Director of the Museum of the Geological Survey of Sweden, at Stockholm.[9] Values are: $d=2.83$; $J_{rn}=2.5\times10^{-3}$; $K_0\ (f)=$

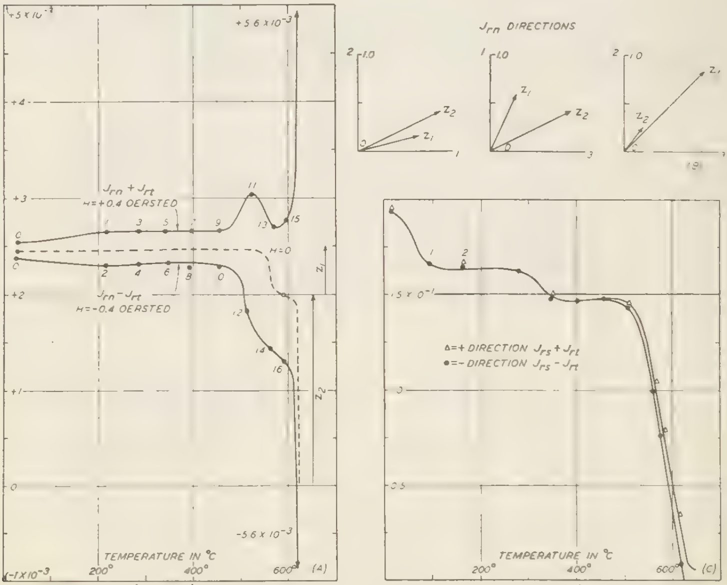


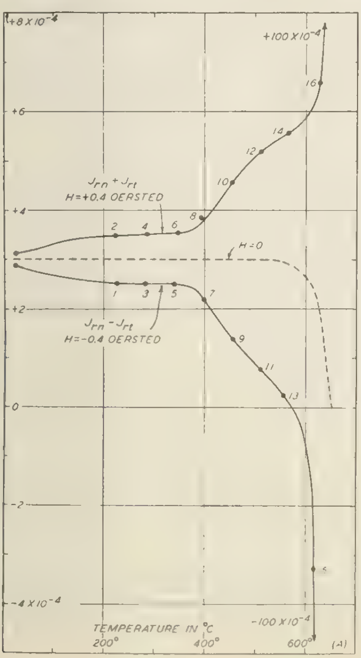
FIG. 7—VALUES OF ($J_{rn}\pm J_{rt}$), DIRECTIONS OF J_{rn}, AND VALUES OF J_{rs} FOR HYPERITE: (A) ($J_{rn}\pm J_{rt}$) MEASURED PARALLEL TO SIDE 2—PROBABLE VALUES FOR H=0 SHOWN DOTTED; (B) RESULTANTS OF ($J_{rn}\pm J_{rt}$) MEASURED FOR SIDES 1, 2, AND 3 OF CUBE, FOR VALUES z_1 AND z_2 OF (A); (C) CHANGE OF J_{rs} WITH TEMPERATURE

8.4×10^{-4}; $Q_n=6.6$; $K_0(h)=6.5\times10^{-4}$; $J_{rc}(h)=5.6\times10^{-3}$; $Q_t=18$; $Q_{nt}=0.37$; $J_{rs}(h)=1.95\times10^{-1}$; $R(h)=2850$; $S(h)=35$; $H_c(h)=360$. For new cube: $J_{rs}(f)=2.15\times10^{-1}$; $H_c(f)=400$; $R(f)=2550$. The disappearance of J_{rs} with decreasing temperature (Fig. 7, *C*) is about the same for the two directions ($\pm$) of the field of 0.4 oersted, and the final value is practically reached after an hour of heating. The effect, therefore, is principally due to temperature. The absence of the partial maxima in ($J_{rn}\pm J_{rt}$) could be explained either by the existence of very homogeneous magnetite-crystal grains, better and more uniformly formed than the unicrystal-grains measured (Fig. 1, *B-a*)— grains so small that H_c becomes sufficiently large to permit no decrease of J_{rt} up to 400°C and only a small value for J_{rs}, or else it must be supposed that the mag-

[9]All the rocks from Sweden were kindly furnished by Museiförestanderen A. H. Westergard.

netite is titaniferous. The latter hypothesis is the much more probable since large homogeneous magnetite crystals should show a uniform decrease of (Fig. 1, *B-a*); but here the remanence remains constant up to 470°C as in Figure 6 and thereafter changes take place. The value of J_{rs} of the heated material shows maxima such as are observed in the case of grains of artificial magnetite. For the first case, this might be explained by the formation of cracks in the magnetite, thus producing smaller grains. In the case of the second hypothesis, the titaniferous magnetite breaks down into normal magnetite and ilmenite, as it is known to have a tendency to do (as first revealed by microscopical study, and has now been observed also from the magnetic behavior of titanomagnetite).

If the first hypothesis is true, the coercive force H_c and the quotient $(J_{rs}/K_0H)=R$ would be much lower than it is. In the first case H_c increases and in the second it decreases after heating. All the data given in the beginning point therefore to the second case. Pure magnetite in the laboratory shows a slow spontaneous decrease in J_{rs} with temperature not found for titaniferous material. Old rocks with more or less pure magnetite (Curie point = 530° to 580°C) have little remanence and a small value of Q_n, while old titanomagnetite, as from Buon Accord, has large values of remanence and Q_n. All criteria, therefore, point to the existence of titaniferous magnetite, the persistent remanence of which does not permit a certain determination of age with certainty. Figure 7-*B* shows the change of direction for J_{rn} due to movements between 700°C and 500°C, z_2 being the component for ferromagnetic material



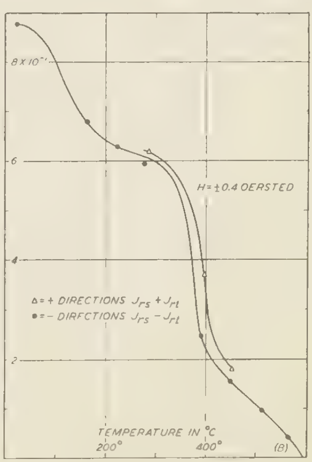


FIG. 8—VALUES OF $(J_{rn} \pm J_{rt})$ AND OF J_{rs} FOR OLIVINDIABASE

with T_c between 700° and 600°C and z_1 being for magnetites with T_c below 600°C.

(3) *Olivindiabase dyke* (Fig. 8)—From west of Astano, Ticino, Switzerland, probably precarboniferous, kindly supplied by Prof. M. Reinhard of Basel, Switzerland. Values are: J_{rn} (resultant value) $= 4.8 \times 10^{-4}$; $K_0(f) = 6.7 \times 10^{-4}$; $Q_n = 1.5$; $K_0(h) = 7.7 \times 10^{-4}$; $J_{rt} = 100 \times 10^{-4}$; $Q_t = 28$; $Q_{nt} = 0.27$; $J_{rs}(h) = 9.0 \times 10^{-1}$; $R(h) = 1100$; $S = 90$; $H_c(h) = 740$; Curie point $= 630$°C. Material was lacking for a second cube for examination of J_{rs}, R, and H_c of fresh rock. The fact that J_{rn} (Fig. 8, curves A) remains constant up to 400°C, the very high values of R, H_c, Q_t, J_{rc}, and $T_c = 630$°C, point to an admixture of much TiO_2. The curves B of Figure 8 for J_{rs} show a relatively weak maximum at 250°C with a secondary weak maximum at 450°C. The principal ferromagnetic mineral of the heated rock is therefore normal magnetite unmixed from the titanomagnetite. As the ferromagnetic material has especially high values of T_c and H_c, the small value of Q_{nt} indicates an old rock. However, an examination of additional cubes and of the direction for z_1 and z_2 (like those in Fig. 7) would be necessary to determine whether this Alpine-dyke rock had not been strongly crushed and kneaded, thus losing some of its residual magnetism.

(4) Diabase (Fig. 9)—Asby type from Angermanland, Sweden; post-archaic, precambrian. Values are: $d = 2.97$; $J_{rn} = 3.3 \times 10^{-3}$ (re-

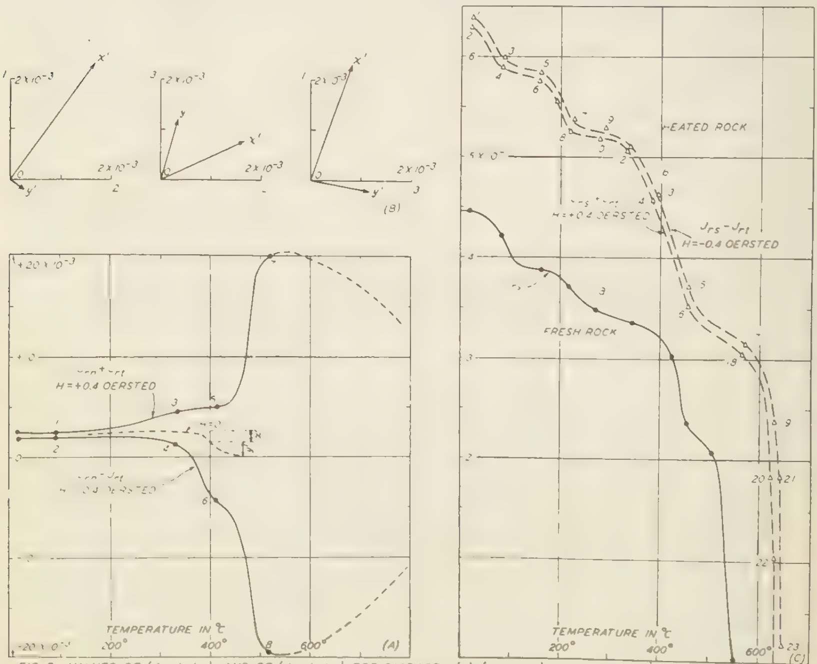


FIG. 9—VALUES OF ($J_{rn} \pm J_{rt}$) AND OF ($J_{rs} \pm J_{rt}$) FOR DIABASE: (A) ($J_{rn} \pm J_{rt}$) MEASURED PARALLEL TO SIDE 1—PROBABLE VALUES FOR H=0 SHOWN DOTTED; (B) DIRECTIONS x' AND y' FOR SIDES 1, 2, AND 3 OF CUBE; (C) CHANGE OF J_{rs} WITH TEMPERATURE

sultant value); $K_0(f)=2.7\times10^{-3}$; $Q_n=2.7$; $K_0(h)=2.4\times10^{-3}$; $J_{rc}=2.0\times10^{-2}$; $Q_t=17$; $Q_{nt}=0.16$; $J_{rs}(h)=1.26$; $R(h)=520$; $S=60$; $H_c(h)=290$; Curie point $=580°C(?)$. For new cube: $J_{rs}(f)=0.44$; $H_c(f)=320$; $J_{rs}(h)=0.67$; $H_c(h)=290$. The curves A of Figure 9 for $(J_{rn}\pm J_{rt})$, their independence of temperature up to 350°C and their shape for higher temperatures, the higher values of R, H_c, Q_t, T_c at 560°C, and the decrease of H_c after the first heating to 700°C, all indicate magnetite with high content of titanium, containing some FeO. After heating, the curve C for J_{rs} was displaced slightly for higher temperatures and the maxima at 150°, 300°, and 500°C were more pronounced than for a fresh rock. J_{rs} (not J_{rc}) was higher than before heating (curve a), because the grains were subdivided by newly formed ilmenite lamellae and hence are of smaller size.

The directions for $x=\{J_{rn}-[J_{rn}-J_{rt}\ (420°C)]\}$ and for $y=\}[J_{rn}-J_{rt}\ (420°C)]\{$ are very different and indicate strong movements between 420°C and 520°C; however, such old rocks may possibly have been moved and heated a second time only to 420°C in another geological period. No account of this has been taken heretofore. The low value of Q_{nt} may be due to the old age as well as to the weakening of J_{rn} through movements.

(5) *Quartz-porphyry* (Fig. 10) -From Kollmen, Wurtzen, Saxony, Germany; upper permian. The cubes II, III, and IV of 4-cm side were cut from a large sample to test the homogeneity of the material. The orientation was not noted. Cubes I, V, and VI were cut from other samples from the same locality. Values are: J_{rn} (resultant value) $=3.9\times10^{-5}$ for I, 1.6×10^{-4} for II, 3.1×10^{-5} for III, 6.6×10^{-5} for IV, 7×10^{-6} for V, 2.5×10^{-4} for VI; $K_0(f)=2.0\times10^{-4}$ for I, II, III, and IV, 1.7×10^{-4} for V, 4.3×10^{-4} for VI; $Q_n=0.43$ for I, 0.18 for II, 0.35 for III, 0.72 for IV, 0.10 for V, 1.25 for VI; $J_{rc}(h)$ (this depends on the time of heating and is highest when all changes have taken place and is therefore only relative) $=1.2\times10^{-3}$ for I, 1.9×10^{-3} for II, 1.6×10^{-3} for III, 2.1×10^{-3} for IV, 2.1×10^{-3} for V, 2.5×10^{-3} for VI; $S(h)=42$ for I, 49 for II; $K_0(h)=2.0\times10^{-4}$ for I, 5.2×10^{-4} for II, 4.0×10^{-4} for IV, 6×10^{-4} for V (corresponding to the values of J_{rc} after long period of heating); $J_{rs}(h)=5.1\times10^{-2}$ for I, 9.4×10^{-2} for II, 1.7×10^{-2} for V; $H_c(h)=330$ for I, 330 for II, 500 for VI. For new cube: $J_{rs}(f)=3.7\times10^{-2}$, $H_c(f)=270$, $R(f)=185$. The differences for II, III, and IV in J_{rn}, while J_{rc} and K_0 remain approximately the same, are characteristic of movements; the highest value for J_{rn} and Q_{nt} must be the best.

The segments a of the curves in Figure 10 show the probable values if heating could be effected instantaneously.

The curves for $(J_{rn}\pm J_{rt})$ are approximately the same for all cubes measured. The relatively small changes in J_{rn} up to 400°C (compare curve A of Fig. 10 with Figs 1, 2, and 6), as well as the values of H_c and R, indicate TiO_2 in magnetite (compare Fig. 6) and a small excess of FeO since T_c is about 550° to 600°C. As there is little crystallization-remanence (see class III) a larger excess of Fe_2O_3 is improbable. As to the unmixing of TiO_2, the value of J_{rc} for unmixed material can only be surmised; it is perhaps 15 to 20×10^{-5}, with Q_{nt} accordingly about 0.1 — a value that might be expected for permian rock of such magnetite-content when cooled in the Earth's normal field. After heating to 650°C for one-half hour or to 550°C for two hours, the change to normal mag-

netite is completed as is shown by the curve B of Figure 10 for $[J_{rc}\ (600°C) \pm J_{rt}(t°)]$ for II, which is approximately the same as for normal artificial magnetite (Fig. 1, A-a) with T_c between 550°C and 600°C. The curve C for J_{rs} of fresh material is typical for magnetite with a low percentage of TiO_2.

(6) *Porphyry with quartz and mica* (Fig. 11)—From Kaisitz, Lomatzsch, Saxony, a permian. Three cubes of 4-cm side were cut from a large sample. The orientation was not noted. Values are: J_{rt} (resultant) $= 1.2 \times 10^{-4}$ for I, 1.4×10^{-4} for II, 1.4×10^{-4} for III; $K_0(f) = 4.2 \times 10^{-5}$ for I, 5.3×10^{-5} for II, 3.8×10^{-5} for III; $Q_n = 8.4$ for I, 5.0 for II, 8.2 for III; $J_{rs} = 3.3 \times 10^{-4}$ for I, 2.8×10^{-4} for II, 2.7×10^{-4} for III; $K_0(h) = 3.0 \times 10^{-5}$ for I, 4.1×10^{-5} for II, 4.0×10^{-5} for III; $Q_t(h) = 25$ for I, 15 for II, 15 for III; $Q_{nt} = 0.30$ for I, 0.43 for II, 0.52 for III; $J_{rs}(h) = 6.0 \times 10^{-3}$ for I, 10.2×10^{-3} for II, 17×10^{-3} for III; $S = 18$ for I, 36 for II, 63 for III; $H_c(h) = 500$ for I, 530 for II, 540 for III; $R(h) = 250$ for II, 420 for III. For new cube: $J_{rs}(f) = 1.1 \times 10^{-2}$; $R(f) = 225$; $H(f) = 520$. For I, II, III, T_c is between 560° and 580°C. No movements were observed on dissecting another cube with the same constants in smaller cubes.

Another cube B, labeled as taken from the same locality, showed ferromagnetism with quite different parameters, belonging to class III, as follows: $J_{rn} = 7.7 \times 10^{-4}$; $K = 2.0 \times 10^{-5}$; $Q_n = 85$; $J_{rt} = 7.5 \times 10^{-4}$; $Q_t = 83$; $Q_{nt} = 1.0$; Figure 10-B for $(J_{rn} \pm J_{rt})$ is characteristic of another kind of magnetite (see Figs. 11, 12, 13).

The curves for I and II for $(J_{rn} \pm J_{rt})$ are given in Figure 11, A, and the high characteristic values of R, H_c, and T_c indicate a magnetite with much TiO_2 and little or no excess of Fe_2O_3 and little FeO. Q_{nt} has a value 0.30 to 0.50, which might be expected for such a magnetite in a permian rock. Cube IV contains magnetite with much TiO_2 and Fe_2O_3, as shown by the irreversible changes, and gives some crystallization-remanence in the curve between 100° and 400°C, $T_c > 600°$, hence no useful value of J_{rc} can be obtained from this cube.

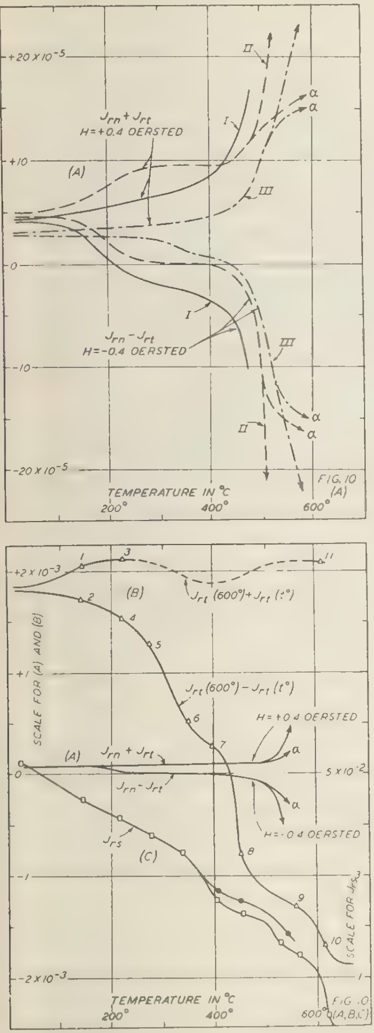
§ 2. (III)—The third group consists of rocks with large irreversible decrease of J_{rn} with heating, J_{rn} vanishing when sample is heated to 300°C and above, the average typical constants and T_c having low or high values but always large changes of R after heating.

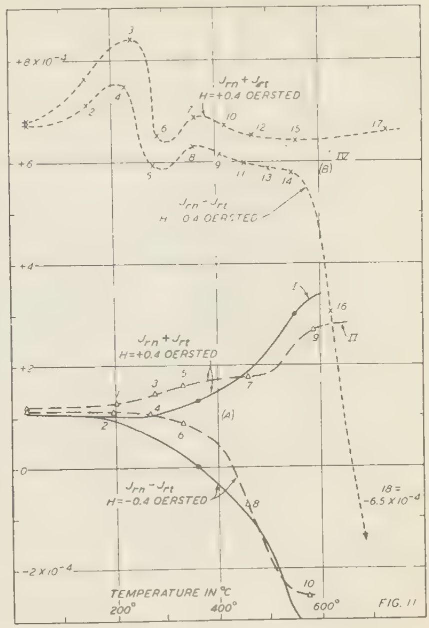
These rocks cannot be used for determining the Earth's field because the value J_{rc} of fresh rock cannot be measured and because it is doubtful whether the present composition of these magnetites and therefore also the remanence is the original one.

(A) With T_c about $585° \pm 30°C$ and rather low typical constants, the curves (for example, Fig. 11) show J_{rn} vanishing by heating also for +0.4 oersted but there is a strong impression of the outer field during heating giving rise to crystallization-remanence (see Part I, § 5).

(1) *Gabbro* (Fig. 12)—From Hognäs, Västerbottans Län, Malå, Sweden, precambrian. Values are: $J_{rn} = 2.9 \times 10^{-3}$; $K_0(f) = 4.1 \times 10^{-3}$; $Q_n = 1.5$; $K_0(h) = 3.9 \times 10^{-3}$; $J_{rc}(h) = 3.5 \times 10^{-3}$; $Q_t = 2.0$; $Q_{nt} = 0.83$; $J_{rs}(h) = 2.5 \times 10^{-1}$; $R(h) = 65$; $J_{rn} = 2.3 \times 10^{-3}$; $J_{rs}(f) = 1.8 \times 10^{-1}$; $H_c(f) = 150$; $R(f) = 44$.

(2) *Diabase* (Fig. 13)—From Byklev, Hunneberg, Alvoberg Län, Västergotland, Sweden, post-siluric. The natural residual magnetism of (2) is about zero. The curves of Figures 12 and 13 show crystallization-





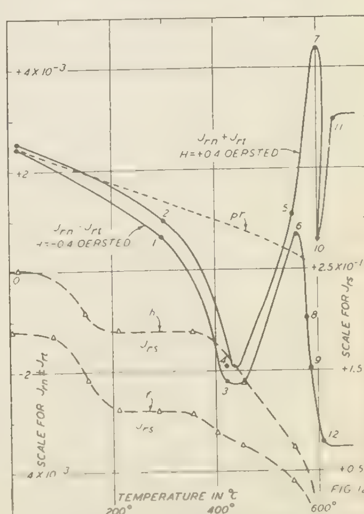
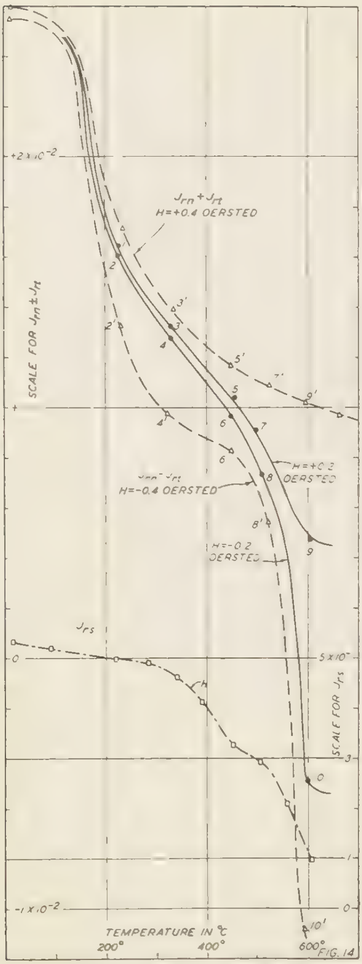
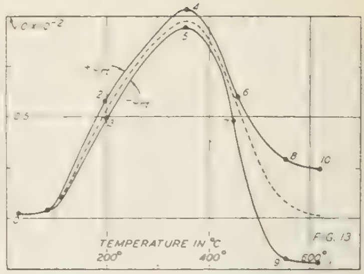


FIG. 10—VALUES OF ($J_{rn} \pm J_{rt}$) AND OF J_{rs} FOR QUARTZ PORPHYRY: (A) ($J_{rn} \pm J_{rt}$) FOR SPECIMENS I, II, AND III; (B) VARIATION OF [J_{rt} (650°C) ± J_{rt}] WITH TEMPERATURE—HEATED SPECIMEN; (C) J_{rs} FOR FRESH SPECIMEN

FIG. 11—VALUES OF ($J_{rn} \pm J_{rt}$) FOR THREE SPECIMENS OF QUARTZ PORPHYRY

FIG. 12—VALUES OF ($J_{rn} \pm J_{rt}$) AND OF J_{rs} FOR GABBRO





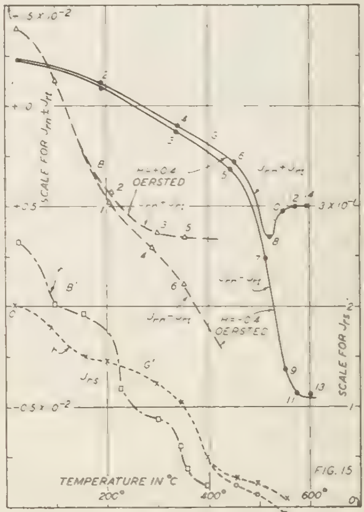


FIG. 13—VALUES OF $\pm J_{rt}$ FOR DIABASE

FIG. 14—VALUES OF $(J_{rn}\pm J_{rt})$ AND OF J_{rs} FOR GABBRO

FIG. 15—VALUES OF $(J_{rn}\pm J_{rt})$ AND OF J_{rs} FOR GABBRO (G, G') AND BASALT (B, B')

remanence produced by a magnetic field $+0.4$ oersted during unmixing of the magnetite resulting from heating. The magnetic field at the first heating to a given temperature $t°$ imparts a large crystallization-remanence J_{rl} during the formation of the new space-lattice. This value of J_{rl} is much higher and stronger than the thermoremanence J_{rt} at the same temperature and field and, therefore, cannot be notably decreased by the opposing field -0.4 oersted at temperature $t°$. Above 350°C the changes are completed and J_{rt} becomes greater at higher temperatures than the impressed value of J_{rl}. The value of J_{rl} first decreases then disappears, and finally only the values of $\pm J_{rt}$ for a field of ± 0.4 oersted remain. The ferromagnetic material of (1) becomes normal magnetite, as

is seen in Figure 12, by the heating curve for J_{rs} for unmixed material using a field of -0.4 oersted. In the case of fresh material, J_{rs} decreases rapidly by unmixing, as may be more clearly seen in Figures 15, 16, and 17.

In Figure 12 the sequence was changed at points 5 and 10. The value at 300°C remained the same if the specimen was heated two or three times to the same temperature. At a given temperature unmixing reaches a limit in less than 20 minutes, and consequently only some grains or some parts of the sample are involved. The separated molecules which are not stable in the space-lattice at the temperature produced by heating at atmospheric pressure and in the absence of water, are probably Fe_2O_3 [I, 1935*f*]. Whether the Fe_2O_3-molecules in excess were introduced into the lattice during the first crystallization of the magnetite or by a later change, for example, or by action of water, is not known. Just as crystallization-remanence is brought about by unmixing, J_{rn} may be produced in such rocks by any of the changes mentioned above.

(*B*) *Curves showing no effect of the outer field during the change:* (1) *Gabbro* (Fig. 14)—From Craig, Craggen, Mull, Scotland, tertiary, kindly furnished by Prof. A. Harker, Cambridge, England. Values are: J_{rn} (resultant) $=4.2\times10^{-2}$; $K_0(f)=3.05\times10^{-4}$; $Q_n=300$; $J_{rc}=1.1\times10^{-2}(?)$; $J_{rs}(h)=5.3\times10^{-1}$; $R(h)=1700$; $S(h)=48$; Curie point >620°C.

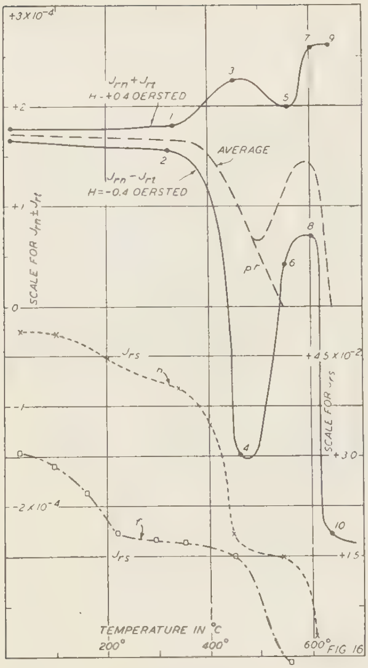
(2) *Gabbro* (Fig. 15)—From Summit Bridein Druim, Cuillin Hills, Skye, Great Britain, tertiary, by Prof. A. Harker, Cambridge, England. Values are: $J_{rn}(t)=1.20\times10^{-2}$; $K_0(f)=9.4\times10^{-4}$; $Q_n=29$; $K_0(h)=7.6\times10^{-4}$; $J_{rc}(h)=4.9\times10^{-3}$; $Q_t(h)=21$; $J_{rs}(h)=3.2\times10^{-1}$; $R(h)=420$; $S(h)=65$; $H_c(h)=290$; Curie point $(h)=580$°C. For new cube: $J_{rs}(f)=4.4\times10^{-1}$; $R(f)=470$; $H_c(f)=370$.

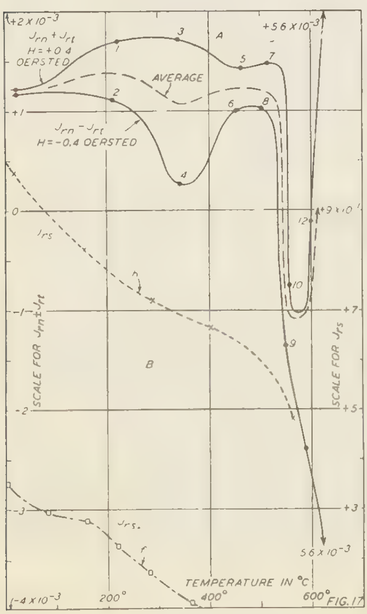
A strong decrease for $(J_{rn}\pm J_{rt})$ is produced immediately by heating, that is, some disturbance of the space-lattice by separation of unknown molecules. A crystallization-remanence similar to that of rocks under *A* is not observable. The high values of the typical constants as far as observed—only one cube was available—indicate the presence of TiO_2(?) in the magnetite, part of which remains after heating as proved by the slow decrease of J_{rs} to 300°C (Fig. 15, curve G', and Fig. 14) and $T_c>610$°C. The typical constants of (2) and consequently T_c are lower than those of (1). Q_n is very high, as is to be expected in the case of recent rocks with high TiO_2-content.

(3) *Basalt, enclosed in tertiary gabbro and metamorphosized* (Fig. 14, *B*)—From Sgurr Sgumain, Cuillin Hills, Skye, Great Britain. Values are: $J_{rn}=1.4\times10^{-2}$; $K_0(f)=3.0\times10^{-3}$; $Q_n=11$; $K_0(h)=3.0\times10^{-3}$; $J_{rt}(h)=4\times10^{-3}(?)$; $J_{rs}(h)=2.0\times10^{-1}$; $R(h)=66$; $S=50$; $H_c(h)=230$. For new cubes: $J_{rs}(f)=2.7\times10^{-1}$; $R(f)=90(?)$. The typical constants are low, the changes by heating are not large, and $T_c<500$°C for the $(J_{rn}-J_{rt})$-curve as well as for the J_{rs}-curve B' for fresh material. It also remains below 580°C for heated material, indicating an admixture similar to FeO (for example, MgO) in some of the magnetites.

(*C*) Rocks with irreversible decrease at temperatures above 350°C have below 350°C the curves and typical constants of class I or class II.

(1) *Gabbro* (Fig. 16)—From Loftahammar, Kalmar Län, Småland, Sweden. Values are: $d=3.05$; J_{rn} (total) $=1.9\times10^{-3}$; $K_0(f)=4.4\times10^{-4}$; $Q_n=9.5$; $K_0(h)=1.1\times10^{-4}$; $J_{rc}=2.3\times10^{-3}(?)$; $Q_t(h)=4.6$; $J_{rs}(h)=$





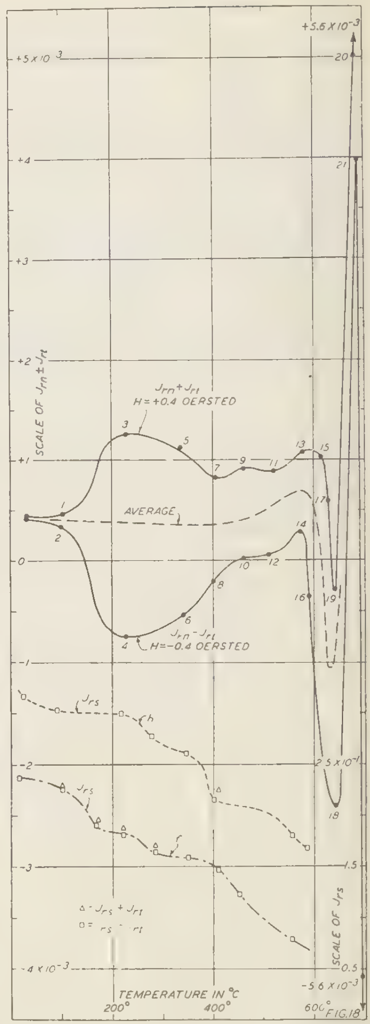


FIG. 16—VALUES OF $(J_{rn} \pm J_{rt})$ AND OF J_{rs} FOR GABBRO

FIG. 17—VALUES OF $(J_{rn} \pm J_{rt})$ AND OF J_{rs} FOR BASALT

FIG. 18—VALUES OF $(J_{rn} \pm J_{rt})$ AND OF J_{rs} FOR LAURDALITE

4.8×10^{-2}; $R(h)=420$; $S(h)=21$; $H_c(h)=390$ oersted; Curie point $(h)=620°C$. For new cube: $J_{rs}(f)=3.1\times10^{-2}$; $H_c(f)=175$; $R(f)=70$; $J_{rs}(h)=4.3\times10^{-2}$.

(2) *Basalt* (Fig. 17)—From northeast of Bombay, India, postmesozoic, kindly furnished by Dr. M. Mühlberg, Aarau, Switzerland. Values are: $d=2.8$; J_{rn} (resultant) $=1.20\times10^{-3}$; $K_0(f)=4.5\times10^{-3}$; $Q_n=0.62$; $K_0(h)=3.2\times10^{-3}$; $J_{rc}=5.6\times10^{-3}$; $Q_t=3.9$; $Q_{nt}=0.16$; $J_{rs}(h)=7.6\times10^{-1}$ to 10×10^{-1}; $R(h)=235$; $S=130$; $H_c(h)=370$; Curie point $=620°C$. For new cube: $J_{rs}(f)=3.5\times10^{-1}$; $R(f)=78$. The marked changes of slope of the curves $(J_{rn}\pm J_{rt})$ between 200° and 500°C depending upon the sequence of heating in the field ±0.4 oersted indicate some unmixing as for type A, which is not complete. The remaining percentage, perhaps due to another admixture, begins to unmix, or unmixing becomes marked through sufficient reaction-velocity only above 500°C. The J_{rs}-curve for fresh material drops rapidly for (1) to 450°C and for (2) to 500°C, probably because the partial unmixing disturbs the lattice and not because of low Curie point.

(3) *Laurdalite* (Fig. 18)—From Laugendal, Langensund, Norway, premesozoic. Values are: $d=2.45$; J_{rn} (resultant) $=3.8\times10^{-4}$; $K_0(f)=3.8\times10^{-3}$; $Q_n=0.22$; $K_0(h)=3.3\times10^{-3}$; $J_{rt}=5.6\times10^{-3}$; $Q_t=3.3$; $Q_{nt}=0.07$; $J_{rs}(h)=2.6\times10^{-1}$; $R(h)=8.0$; $S(h)=46$; $H_c(h)=160$; $T_c=620°C$ (prevailing for fresh rock) and 720°C (for heated rock). For new cube $J_{rs}(f)=2.2\times10^{-2}$; $H_c(f)=105$; $R(f)=60$. The curve $(J_{rn}\pm J_{rt})$ above 350°C indicates a small admixture in some magnetites like that of type A; the curve below 350°C and the low typical constants indicate a normal magnetite. The J_{rs}-curves for fresh and heated material furnish grounds for assuming some hitherto unmeasured ferromagnetic material of high T_c (kind of magnetite?) but of low typical constants. This rock is an example of an intricate problem in ferromagnetic-analysis of rocks.

Addendum

A few European sediments tested ($K=2\times10^{-5}$) have no appreciable value of J_{rn}. According to E. D. Lynton [II, 1937 *e* and 1938 *b*], some American sediments, shales, and sands, with heavy black minerals distributed throughout. have so great a value of J_{rn} that its direction can be determined to $\pm2°$; data on this point have not been given. The manner in which such a polarity was acquired is not known. The following hypotheses appear possible: (1) The grains of magnetite which are freed by the erosion of eruptive rocks may be oriented by the Earth's magnetic field while falling to the bottom of the sea or while in wet mud; (2) after sedimentation under heavy pressures of deep water, or under special chemical conditions, oxidation, or reduction, new iron minerals are formed and strong crystallization-remanence, due to the Earth's field [Part I, § 5], can arise in the magnetite during such a process; (3) the Earth's field may impose a new remanence on the grains of magnetite, which are randomly oriented, under high pressures (this hypothesis appears less probable since such pressures do not produce a notable change in T_c [I, 1931 *f*]).

Maghemite ($\gamma-Fe_2O_3$) becomes somewhat stable owing to different admixtures in the space-lattice [II, 1929 and 1937 *d*]. The value $T_c=675°C$ is about the same for pure maghemite and hematite ($\alpha-Fe_2O_3$) [II, 1937 *c*].

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GEOMAGNETISM OR TERRESTRIAL MAGNETISM?

By S. Chapman

The purpose of this Note is to suggest to workers on the science of the Earth's magnetism, who write in English, that they should regularly adopt the title *geomagnetism*, and the corresponding adjective *geomagnetic*, in place of the more usual *terrestrial magnetism* and *terrestrial magnetic*. The adjective geomagnetic is already commonly used in connection with the angular coordinates of position on the globe, relative to the Earth's magnetic axis; but in other connections, at present, it occurs seldom.

I am not enough of a historian to know when the title terrestrial magnetism became general, or why it ever gained vogue, when the old words geography and geology already offered analogies for the word geomagnetism. But apart from the stylistic literary objection to the combination of a Latin adjective *terrestrial* with a noun originally Greek —an argument which to many scientists may not have much appeal —the use of the Greek earth-prefix *geo* with the main noun *magnetism*, in line with the nomenclature for geography, geodesy, geophysics and geology, has the great advantage of convenience, brevity, and ease of speech. The adjectival form of the word, *geomagnetic*, has a still greater convenience over the awkward adjectival phrase *terrestrial magnetic*, in which the second adjective is qualified by the separate subadjective *terrestrial*.

It would therefore seem to me wise to drop the present usage altogether. As regards languages other than English, the change in French from *magnétisme terrestre* to *géomagnétisme* would seem equally advantageous. In German the existing word Erdmagnetismus, though a linguistic hybrid, has all the advantages of brevity and convenience offered by Geomagnetismus, and there would seem to be no reason for change. By analogy, in English, the adoption of the word *earth-magnetism* might be suggested, but this seems undesirable, since the word is longer to write and harder to pronounce than *geomagnetism*, quite apart from the stylistic argument for the latter.

There is something also to be said for the use of the words *geoelectric* and *geoelectricity* in reference to the science of the electricity of the whole Earth, including earth-currents and earth-potentials as well as the electricity of the atmosphere.

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REVIEWS AND ABSTRACTS

ERWIN MIEHLNICKEL: *Höhenstrahlung* (Ultrastrahlung). Dresden und Leipzig, Verlag von Theodor Steinkopff, 1938 (xvi+316 mit 69 Abbildungen). 22 cm.

The study of cosmic rays is a branch of modern physics which is demanding increasing attention among physicists. The large number of contributions to the subject which have appeared in recent years amply justifies a publication setting forth the present status of research in this field.

The volume before us provides a comprehensive summary of practically all the results of cosmic-ray investigations which had been published up to the end of 1937. The task involved in carefully surveying the existing literature in a field which has so rapidly attracted investigators, is evidenced by the fact that the bibliographies following each of the 17 chapters of Dr. Miehlnickel's book comprise a total of nearly 2900 references. The listing of these both according to subject and author, at the end of the volume, should in itself make this a valuable reference-book for all cosmic-ray investigators.

The author treats the subject from the viewpoint of the physicist engaged in the study of radiation. The work falls into five general divisions, each of which receives about equal emphasis, as follows: (1) Physical conditions on the Earth, stars, nebulae, etc., which have a possible bearing on the origin and measurements of cosmic-rays; (2) technique of measurement; (3) characteristics of the radiation (intensity, direction, hardness, etc.); (4) behavior of the radiation in fields of force and in matter; and (5) the constitution of the primary and secondary rays and their origin. The general treatment is preceded by a historical review of cosmic-ray research. Numerous well-selected illustrations and tables aid in the presentation of the subject-matter. Tables of symbols and constants used in the text have also been included. The care exercised in the preparation of this work is evident from the fact that no significant aspect of cosmic-ray research appears to have been overlooked.

The reviewer heartily recommends the book to any reader who desires to familiarize himself with the present status of cosmic-ray research.

S. E. FORBUSH

S. K. BANERJI: *Does thunderstorm rain play any part in the replenishment of the Earth's negative charge?* London, Q. J. R. Met. Soc., v. 64, 1938 (293-299 with 3 figs.).

Answering his own question, Dr. Banerji concludes that the rain of thunder-storms does play a part in the replenishment of the Earth's negative charge, as a result of the study of 23 thunder-storms over Bombay in the years 1930-32. Rainfall was recorded by the pluviograph and the electric charge by apparatus similar to that used by Simpson at Simla in 1908 and 1909. Eleven of the storms transferred an excess of positive charge to the Earth and twelve an excess of negative charge, but the excess of negative charge brought to each cm^2 of ground in these twelve storms was much greater than the excess of positive charge per cm^2 in the other eleven. Estimating that an area 100 km square received charge at the same rate as recorded at Bombay, the author concludes that, on the average (using all 23 storms) there was transferred to ground an excess of about 2000 coulombs of negative electricity per thunder-storm.

Dr. Banjeri mentions that thunder-storms at Bombay invariably move overhead in some east-west or west-east direction, according as they are "heat" thunder-storms formed on the mainland between the station and the Western Ghats, or "line-squall" thunder-storms advancing from the sea towards land. And he also states that the more active part of a storm would sometimes pass to the north or south of the station. In this last remark may perhaps be found the explanation for the excess of negative charge observed at Bombay, if we accept the electrical structure of the thunder-cloud proposed by Simpson and Scrase in 1937. According to this proposed structure, the more active part of a thunder-storm is associated with an active center in the forward portion of the base of the cloud where local regions of positive charge are thought to be generated and from which predominantly positively-charged rain falls. The less active part of the storm is associated with the side and rear portions of the cloud from which predominantly negative rain falls. It seems not inappropriate to designate the more active portion only of the storm as a *thunder-storm* and the less active portion as the *thunder-shower*. Dr. Banerji's findings of preponderantly negatively-charged rain during

thunder-storms may be considerably affected by the fact that the active part of a storm did sometimes pass to the north or the south of the station, so that more often than not he was making observations on thunder-shower rain than on thunder-storm rain. Scrase, in Geophysical Memoir No. 75 of the British Meteorological Office, 1938, shows that the Kew thunder-shower rain is preponderantly negatively charged, and the Kew and Bombay results would, therefore, be in agreement if Dr. Banerji's results might be ascribed largely to thunder-shower rain rather than to thunder-storm rain.

If, as the results of Scrase show, we must contend with differing electrical conditions for the different kinds of precipitation—such as instability rains, thunder-showers, thunder-storms, and continuous rains—it seems necessary to obtain continuous automatic registration of rainfall and charge at several suitable stations for many years, before an adequate attempt can be made to determine how important a factor the charge brought down by rain may be in the general exchange of electricity between the Earth and the atmosphere. O. W. Torreson

F. J. Scrase: *Electricity on rain: A discussion of records obtained at Kew Observatory*, 1935-6. London, Met. Office, Geophys. Mem., No. 75, 1938 (20 with 8 figs.).

The discussion is based on records obtained at Kew Observatory in the two years 1935 and 1936. The apparatus for automatically registering the electric charge brought down by rain was installed toward the end of 1934, as part of a program, initiated by Dr. F. W. J. Whipple, for obtaining continuous records of all of the more important factors in atmospheric electricity. It was realized that only by continuous registration over long periods of time could reliable yearly averages for the amount and sign of electricity brought down by rain be obtained. The records for 1936 are more complete than those for 1935; in 1935 considerable loss was occasioned by insulation-leak. Following the brief introduction, the apparatus is described.

The apparatus consists of three main parts. The rain-receiver; the electrometer with its recording-drum; and the gage for measuring the amount of rain. The rain-receiver is a funnel supported by a sulphur-insulated stand, and electrical connection is made from the funnel to the fiber of a Dolezalek electrometer. A conical shield surrounds the funnel-mouth, and around the shield is a metal cylinder which effectively eliminates the induction-effect of the Earth's electrical field on the apparatus. However, the cylinder partially or completely prevents rain from entering the receiver under varying conditions of wind, and the observations on amount of rainfall must be corrected by a factor of about 50 per cent. The electrometer-deflections are photographically recorded and electric controls and relays operate a light to provide accurate time-marks. The gage for measuring the amount of rain caught is of the tilting-bucket type, the bucket having a volume of a few cc. On each tilting of the bucket an electrical circuit closes and a light makes a spot on the photographic record, while at the same time the electrometer-fiber is earthed briefly. From the record is then readily obtained the amount and sign of electric charge carried by unit-volume of rain and the rate of rainfall.

The results of various analyses are next given, with tables of data to illustrate the findings. Some of the more important results may be mentioned here briefly. In both 1935 and 1936 roughly 30 per cent of the total amount of rain had no measurable charge, somewhat more than 50 per cent had positive charge, and somewhat less than 20 per cent had negative charge. In both years the negatively charged rain was the more highly charged, on the average. Of the total amount of electricity, positive electricity was in excess in 1936 and negative in 1935, but the results in 1935 are not so complete as are those for 1936.

There is a predominance of positive charge on the rain in winter but this predominance tends to diminish or even to disappear in the equinoxes and in summer. Most of the charge brought by rain to unit-area of the Earth at Kew is brought down in the afternoon and least in the morning, which is expected since the most strongly electrified clouds are those produced by convection which tends to occur in the afternoon. With increasing rate of rainfall the ratio of positively to negatively charged rain decreases from high values almost to unity when the rate of fall is as much as 0.2 mm per minute and then, as the rainfall becomes still heavier, the ratio again increases. Another interesting point is that the smaller the charge carried by each cc of rain the greater the preponderance of positively charged rain.

Other results showed that thunder-showers were responsible for most of the high negative charges, while continuous rain and thunder-storms were generally associated with excess of positive charge. The potential-gradient at the ground was much more often negative than positive during positively charged rain, but in negatively charged rain there was no marked tendency for the gradient to be of one sign rather than the other.

To best illustrate the various results outlined above, four records are reproduced in the next section of the paper and discussed in some detail, representing instability showers, thunder-storms, thunder-showers, and continuous rains.

A discussion then follows of the electrical structure of a thunder-cloud as proposed by Simpson and Scrase in a paper in the Proceedings of the Royal Society, London, in August, 1937. The results of the present paper appear to support the view that the electrification of shower-clouds is brought about by the impact of ice-crystals. The author suggests that the same process is responsible for the initial separation of electricity in a thunder-cloud but that, as a result of the more violent ascent of air, local regions of positive charge are generated near the base and in the forward part of the thunder-cloud by the breaking-drop process. The author finally points out that it is not clear how the electrification of continuous rain is produced but makes the suggestion that the prevalence of negative potential-gradient in this type of rain is the result rather than the cause of the transfer of positive charge from the clouds to the ground by rain.

In reviewing this paper one is impressed with the efficacy and value of continuous automatic recording of geophysical phenomena over long periods, as compared with eye-observations on separate occasions. In the past 40 years perhaps ten or twelve investigators have studied the electricity associated with thunder-storms and rain, but most of these have studied selected disturbed periods and have thus obtained results which may not be truly representative of their respective regions as to contribution of bad-weather electricity to the general electrical conditions of the regions. Sir George Simpson at Simla in 1908 and 1909 and Schindelhauer at Potsdam in 1909 to 1911 contributed the most notable investigations among earlier investigators with their continuous records over long periods. The results of the various investigators are not in accord; some say that on the whole more positive than negative electricity is carried to the Earth by rain, while others say the reverse. Still others say that the positive is balanced by the negative. It is easily seen that different geographical and meteorological conditions at the different observing-stations must make for different rain- and thunder-storm conditions and so for different atmospheric-electric conditions. A more widespread attack on the electrical conditions associated with bad weather seems necessary. Instruments such as that described by Scrase in the present paper should be procurable by a dozen or more stations well distributed over the Earth, as well as the Wilson test-plate and the Wormell point-discharge apparatus which have been in use now for many years at Kew by Dr. Whipple and his colleagues. The unusual electrical conditions associated with bad weather have until recently received too little consideration, but it is becoming increasingly apparent that only by doing more work in that direction will we find an answer to the all-important question as to how the negative charge on the Earth is maintained.

O. W. Torreson

E. M. Bruins: *Cosmische Strahlen in het Aardmagnetisch Veld* (Cosmic rays in the Earth's magnetic field). Dissertation, Amsterdam, 1938.

Dr. E. M. Bruins investigates the features of cosmic rays in the Earth's magnetic field, which have been detected by Clay and his co-workers during a number of voyages on different seas. In Chapter I he treats theoretically the properties of the magnetic center of a body and he applies the results obtained to terrestrial magnetism. The direction of the magnetic axis is found to be latitude 78° 32′ north and longitude 291° 11′ east. The magnetic center has the position in geographical coordinates latitude 6° 31′ north and longitude 161° 45′ east, $r=0.05396$ of the Earth's radius, the secondary axes are directed 7° 29′ north and 160° 56′ east and perpendicular to this direction.

The second chapter treats of the theory of forbidden spaces. Bruins describes the trajectories in the field of a single pole, the forbidden spaces in the field of two poles and of a dipole, and he deduces some particulars of the field of two dipoles. This case is important, because the local disturbances of terrestrial magnetism may be considered as being composed of disturbing unipoles and dipoles.

For the student of terrestrial magnetism the third chapter on "Analysis of experimental data" is most important, because the author deduces the properties of the normal magnetic field. It is clear that we may not make use of the geomagnetic latitude because of the eccentric situation of the dipole. Therefore the author introduces the "eccentric dipole latitude," λ_{ed}. We are now concerned with pure "latitude-effects," λ_g, on the surfaces r-constant, and with pure "distance-effects," ρ, on cones of constant latitude. Curves of constant λ_g and of constant ρ are constructed and formulas for the vertical intensity at the Earth's surface due to the eccentric dipole are deduced. The normal vertical intensity, Z_{dip}, is calculated and by subtracting the values found from those

observed, the anomalies of the field can be deduced. In the regions investigated Bruins establishes the following secondary poles, where δ = distance of pole to Earth's center and p = intensity of the pole in CGS:

Pole	ϕ	λ	Z_{max}	δ	$p \times 10^{-14}$
	°	°			
	+40	−160	0.104	0.81	15
C	+40	− 90	0.103	0.60	68
B	−45	− 40	0.100	0.56	79
	+37	−140	−0.050	0.73	15
D	0	+ 10	−0.132	0.64	71
A	0	−118	−0.051	0.65	26

Each of these poles appears to be strong enough to influence the cosmic rays at the surface. The irregularities in the cosmic-ray distribution found on the voyages from Amsterdam through the Panama Canal to Corral (Chile) and from Amsterdam to Cape Town can be elucidated by the behavior of these secondary poles when taking the combination *AC*, *BD*. And so the features of the cosmic rays show that the magnetic anomalies must be due to a center in the southeastern part of the Atlantic Ocean and in the Pacific Ocean.

The cosmic rays furnish a means of establishing the Earth's magnetic anomalies!

Chapter IV deals with the effect of the quadrupole, which also must be taken into account. An approximate formula for the forbidden spaces can be deduced and a correction for the quadrupole-effect is obtained. This causes a shift of the minima of intensity out of the plane of the equator. The observed shifts can be ascribed to the action of the quadrupole.

The influence of magnetic storms is investigated in Chapter V. The most striking fact is that, during magnetic storms a parallelism occurs very often between cosmic-ray intensity and magnetic horizontal force. We develop the ring-current hypothesis of Störmer up to energies found for cosmic rays. The observed facts may be considered as due to permanent ring-currents in space, which show variations of current-intensity and cause induced currents in the upper atmosphere as well as in the conducting nucleus of the Earth. The currents are present at a distance of two to four Earth-radii.

In Chapter VI the author discusses the hypothesis of Janossy explaining the polar cap of constant intensity found by cosmic-ray measurements at sea-level by the action of the Sun's magnetism. He concludes that it is very improbable that Janossy's theory is right. The reliable data found by Deslandres and Störmer give by far too small magnetic moment of the Sun.

A rather too brief summary in English and an extensive list of references conclude this thorough investigation of the phenomena concerned.

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PROVISIONAL SUNSPOT-NUMBERS FOR MAY TO JULY, 1938

(Dependent alone on observation at Zürich Observatory and its station at Arosa)

Day	May	June	July
1	*E* 115[c]	113	119[ad]
2	134	100[a]	*E* . . .[ac]
3	*E W*160[aaacc]	107[a]	157[a]
4	. . .[aad]	103	151[dd]
5	123	91[d]	141
6	138[a]	*E* 84[ac]	*E* 148[cd]
7	136[d]	*M*134[c]	175[b]
8	*E M*153[ccd]	*W*139[ac]	186[d]
9	156[d]	115	175[d]
10	151[bd]	. . .[a]	183[ab]
11	149	106[b]	205
12	143[ad]	99	211[a]
13	151	. . .[d]	229
14	135[ad]	. . .	*E* 208[bc]
15	131[a]	87	200[a]
16	105	76[d]	173
17	*E* 91[ac]	76	161
18	87[ad]	56[a]	148[d]
19	95	69	*E* 151[ac]
20	*E* . . .[ac]	76	*E M*153[cc]
21	. . .	*E* 103[c]	147
22	. . .[a]	101[ab]	*E* 118[c]
23	119[b]?	98	*M*157[acd]
24	*M*172[aac]	87	. . .[aad]
25	161	76	202
26	*M*152[c]	72	179[a]
27	126	*E E* 108[ccdd]	156
28	. . .	106	151[a]
29	*E M*104[cc]	128	151[aa]
30	89?	119	139[a]
31	*E* 91[acd]		109
Means.	129.5	97.4	166.2
No. days. . . .	26	27	29

Mean for quarter[e] April to June, 1938: 109.0 (83 days)

Note: Middle large bright chromospheric eruption in central zone on May 24, 1938, observed at $16^h\,05^m$ to $16^h\,15^m$, G.M.T.

[a]Passage of an average-sized group through the central meridian.

[b]Passage of a large group or spot through the central meridian.

[c]New formation of a group developing into a middle-sized or large center of activity: *E*, on the eastern part of the Sun's disc; *W*, on the western part; *M*, in the central-circle zone.

[d]Entrance of a large or average-sized center of activity on the east limb.

[e]Mean value for quarter January to March, 1938, should read "*96.8* (*75 days*)" instead of "*98.1* (*71 days*)" as given on page 172 of Terr. Mag., **42**.

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AVERAGES OF CRITICAL FREQUENCIES AND VIRTUAL HEIGHTS OF THE IONOSPHERE, OBSERVED BY THE NATIONAL BUREAU OF STANDARDS, WASHINGTON, D. C., MAY AND JUNE, 1938[1]

The following ionosphere data are in continuation of those published for 1934-36 in this JOURNAL[2]. The symbols used are:

h_E=E-region virtual height, kilometers (lowest measured height)
h_{F_1}=F_1-region virtual height, kilometers (lowest measured height)
h_{F_2}=F_2-region virtual height, kilometers (lowest measured height)
f_E=E-region critical frequency, kilocycles per second, ordinary ray
$f^\circ_{F_1}$=F_1-region critical frequency, kilocycles per second, ordinary ray
$f^x_{F_2}$=F_2-region critical frequency, kilocycles per second, extraordinary ray
EST=Eastern standard time (75° west meridian time); add five hours for Greenwich time
#=Manual measurements
*=Less than ten measurements with automatic recorder

[1]Communicated by the director of the National Bureau of Standards of the United States Department of Commerce.

[2]T. R. Gilliland, S. S. Kirby, N. Smith, and S. E. Reymer, Terr. Mag., 41, 379-388 (1936).

TABLE 1—*Ionosphere data, National Bureau of Standards, Washington, D. C.*

h_E	h_{F_1}	h_{F_2}	f_E	$f^\circ_{F_1}$	$f^x_{F_2}$	h_E	h_{F_1}	h_{F_2}	f_E	$f^\circ_{F_1}$	$f^x_{F_2}$
		May, 1938						*June, 1938*			
		317			7120			291			7230
		317			6720			288			6800
		314			6340			293			6330
		312			6100			298			5940
		316	600#		5710			309	950#		5620
		286	1670#		5800		280	340	1830#		5720
	251	302	2460	3920#	6710		242	360	2570	3990	6420
120	236	315#	2900	4260#	7350	113	228	360	2940	4400#	7170
116	226	355#	3290	4630#	7720	111	224	375	3270	4530#	7580
112	223	400#	3600	4840#	7870	110	216	374	3560	4840#	7640
116	220	406	3740	5070#	8130	110	209	377	3830	5050#	7780
116	220	410	3850	5190#	8330	110	209	403	4000	5220#	7850
114	221	422	3910	5230#	8540	112	205	419	4070	5140#	7950
115	225	423	3880	5220#	8610	113	211	401	4050	5130#	8040
117	231	416	3790	5170#	8620	114	217	406	3930	5130#	8110
117	234	437#	3630	5030#	8710	113	221	387	3740	5050#	8230
118	234	403#	3390	4720#	8810	112	222	377	3480	4830#	8290
121	238	359#	3020	4300#	8480	116	233	358	3090	4550#	8370
	258	323	2510	3810	8530		238	295	2580	4060#	8530
		272			8510			264	2100#		8630
		278			8360			262			8600
		285			8190			269			8350
		296			7830			279			7920
		310			7440			287			7540

NATIONAL BUREAU OF STANDARDS,
UNITED STATES DEPARTMENT OF COMMERCE,
Washington, D. C.

AMERICAN *URSI* BROADCASTS OF COSMIC DATA[1], APRIL TO JUNE, 1938, WITH AMERICAN MAGNETIC CHARACTER-FIGURE C_A, MAY TO JULY, 1938

The data for terrestrial magnetism, sunspots, and solar constant are the same as given in previous tables.

The first three columns of the Table give (1) the magnetic character according to the scale 0-2 of the International Commission of Terrestrial Magnetism and Atmospheric Electricity, (2) the type featuring the day

[1]For previous announcements see Terr. Mag., **35**, 184-185 and 252-253 (1930); **36**, 54, 141, 258-259, and 358-360 (1931); **37**, 85-89, 189-192, 408-411, and 484-487 (1932); **38**, 60-63, 148-151, 262-265, 335-339 (1933); **39**, 73-77, 159-163, 244-247, 353-356 (1934); **40**, 111-115, 220-222, 334-336, 449-452 (1935); **41**, 85-87, 207-209, 315-317, 407-409 (1936); **42**, 89-91, 207-209, 316-319, and 411-415 (1937); **43**, 83-87 and 174-178 (1938).

American magnetic character-figure C_A for Greenwich half-days based on reports from Cheltenham, Honolulu, Huancayo, San Juan, Sitka, Tucson, and Watheroo for May to July, 1938

Day	May		June		July	
	0^h-12^h	12^h-24^h	0^h-12^h	12^h-24^h	0^h-12^h	12^h-24^h
1	0.0	0.2	0.1	0.1	0.7	0.6
2	0.3	0.1	0.1	0.9	0.6	0.1
3	0.4	0.5	0.3	0.1	0.1	0.0
4	0.8	1.1	0.0	0.0	0.2	1.6
5	0.5	0.6	0.4	0.1	0.9	0.6
6	0.4	0.3	0.0	0.2	0.8	0.4
7	0.0	0.0	0.0	0.5	0.0	0.1
8	0.0	0.1	1.2	1.1	0.0	0.0
9	0.0	0.4	0.6	0.6	0.0	0.6
10	0.4	0.1	0.5	0.6	0.9	0.9
11	0.4	1.9	0.6	0.6	0.0	0.1
12	1.7	1.0	0.8	1.1	0.2	0.2
13	0.4	0.0	1.3	0.8	0.2	0.9
14	0.9	1.1	0.6	0.1	0.6[a]	0.6
15	1.0	0.5	0.0	0.0	1.1[b]	1.6
16	0.6	0.4	0.1	0.3[a]	1.1	1.1
17	0.5	0.5	0.0[a]	0.1	0.4	0.1
18	0.3	0.0	0.1	0.0	0.0	0.0
19	0.0	0.0	0.1	0.3	0.2	0.0
20	0.0	0.0	0.0	0.1	0.0	0.1
21	0.4	0.1	0.5	0.5	0.0	0.1
22	0.0	0.1	0.5	0.0	0.1	0.1
23	0.0	0.1	0.0	0.0	0.1	0.1
24	0.1	0.8	0.1	0.1	0.0	0.1
25	0.7	0.4	0.0	0.0	0.1	0.0
26	0.1	0.1	0.1	0.1	0.0	0.0
27	0.0	0.2	0.0	0.1	0.1	0.1
28	0.7	0.8	0.0[a]	0.0	0.0	0.0
29	1.0	1.0	0.0	0.2	0.0	0.4
30	0.3	0.3	0.2[b]	0.3	1.6	0.9
31	0.1	0.0			0.2	0.0
Means	0.4	0.4	0.3	0.3	0.3	0.3
	0.4		0.3		0.3	

[a]San Juan not reporting. [b]Sitka not reporting.

Kennelley-Heaviside Layer heights, Washington, D. C., April to June, 1938
(Nearest hour, Greenwich mean time, of all observations is 17)

Date	Freq.	Ht.	Date	Freq.	Ht.	Date	Freq.	Ht.	Date	Freq.	Ht.
1938	*kc/sec*	*km*	1938	*kc/sec*	*km*	1938	*kc/sec*	*km*	1938	*kc/sec*	*km*
Apr. 6	2,500	120	Apr. 27	4,000	220	May 18	4,200	210	Jun. 8	5,200	610
" "	3,500	150	" "	4,400	240	" "	4,600	240	" "	5,400	670
" "	3,700	*	" "	5,200	320	" "	4,800	310	" "	5,600	330
" "	3,800	300	" "	5,400	340	" "	5,000	520	" "	6,000	740
" "	4,100	220	" "	6,200	340	" "	5,200	390	" "	6,200	820
" "	4,400	260	" "	7,000	380	" "	5,800	350	" "	6,400	*
" "	5,000	280	" "	7,800	400	" "	6,400	380	" 15	2,500	110
" "	5,400	290	" "	7,800	450	" "	6,800	400	" "	4,000	120
" "	7,800	330	" "	8,200	400	" "	6,800	500	" "	4,050	*
" "	9,400	360	" "	8,200	590	" "	7,400	450	" "	4,100	230
" "	10,200	380	" "	8,600	430	" "	7,400	680	" "	4,200	180
" "	10,200	420	" "	8,800	480	" "	7,800	490	" "	5,000	330
" "	11,200	420	" "	9,000	*	" "	8,200	680	" "	5,400	490
" "	11,200	600	May 4	2,500	120	" "	8,400	*	" "	6,200	350
" "	11,600	460	" "	3,600	130	" 25	2,500	110	" "	7,200	390
" "	12,000	600	" "	3,700	*	" "	3,500	130	" "	7,200	420
" "	12,200	*	" "	3,850	280	" "	3,800	160	" "	8,000	430
" 13	2,500	120	" "	4,100	240	" "	3,850	*	" "	8,000	650
" "	3,500	140	" "	4,300	240	" "	3,900	230	" "	8,400	480
" "	3,850	180	" "	4,600	260	" "	4,400	150	" "	8,800	650
" "	3,900	270	" "	4,800	370	" "	4,400	230	" "	9,000	*
" "	4,100	230	" "	5,000	730	" "	5,400	360	" 22	2,500	110
" "	4,400	240	" "	5,200	630	" "	5,600	380	" "	3,500	120
" "	5,400	270	" "	5,600	560	" "	6,200	350	" "	4,000	160
" "	7,000	310	" "	6,000	650	" "	7,000	360	" "	4,130	210
" "	9,400	340	" "	6,200	600	" "	7,800	390	" "	4,400	220
" "	11,000	380	" "	6,600	570	" "	7,800	550	" "	4,800	300
" "	11,000	430	" "	7,000	680	" "	8,200	440	" "	5,000	*
" "	12,000	460	" "	7,200	*	" "	8,600	610	" "	5,200	580
" "	12,000	640	" 11	2,500	120	" "	8,800	*	" "	5,400	470
" "	12,400	510	" "	3,500	130	Jun. 1	2,500	120	" "	6,000	560
" "	12,600	570	" "	3,900	170	" "	3,500	120	" "	6,200	520
" "	12,800	*	" "	3,980	270	" "	3,980	130	" "	6,400	490
" 20	2,500	130	" "	4,200	220	" "	4,000	210	" "	7,000	690
" "	3,500	150	" "	4,800	230	" "	4,400	200	" "	7,200	*
" "	3,650	*	" "	5,200	280	" "	4,600	200	" 29	2,500	110
" "	3,800	230	" "	5,400	340	" "	5,000	340	" "	3,500	120
" "	4,600	250	" "	5,800	390	" "	5,400	440	" "	3,850	150
" "	5,000	290	" "	6,200	320	" "	6,200	380	" "	3,900	*
" "	5,200	340	" "	7,000	350	" "	6,600	410	" "	3,950	210
" "	5,600	350	" "	7,800	370	" "	7,200	440	" "	4,050	*
" "	6,200	390	" "	8,600	390	" "	7,200	580	" "	4,100	260
" "	7,800	420	" "	8,600	460	" "	7,600	480	" "	4,250	180
" "	7,800	450	" "	9,000	450	" "	8,000	590	" "	4,800	280
" "	8,400	420	" "	9,000	500	" "	8,200	*	" "	5,200	570
" "	8,400	550	" "	9,400	460	" 8	2,500	110	" "	5,600	450
" "	9,000	510	" "	9,400	640	" "	3,500	120	" "	6,400	420
" "	9,000	770	" "	9,800	500	" "	3,850	150	" "	7,000	450
" "	9,800	790	" "	10,200	680	" "	3,900	300	" "	7,000	520
" "	9,900	*	" "	10,400	*	" "	4,200	210	" "	7,200	470
" 27	2,500	120	" 18	2,500	120	" "	4,600	240	" "	7,200	720
" "	3,500	120	" "	3,500	130	" "	4,800	320	" "	7,800	550
" "	3,770	170	" "	3,750	160	" "	5,000	630	" "	8,000	*
" "	3,800	260	" "	3,800	260						

* = No value obtained.

other than normal by the letters *b*, *p*, *o*, and *i* for days marked by bay, rapid pulsations, long-period oscillations, and irregular oscillations, respectively, and (3) the hour and minute of Greenwich mean time marking the beginning of a storm, the end of the storm being indicated in the foot-note to the Table. The next two columns give the data relating to sunspots: (1) the number of groups of spots and (2) the total number of spots. It is to be noted that sunspot-numbers such as those from Zürich can be obtained from the number of groups and spots given in the Table by the formula $N=k\ (10g+s)$, where the mean value of k for Mount

Summary American URSI daily broadcasts of cosmic data, April to June, 1938

Greenwich date	April						May						June					
	Magnetism				Sunspot		Magnetism				Sunspot		Magnetism				Sunspot	
	Character	Type	GMT beginning disturbance		Groups	Number	Character	Type	GMT beginning disturbance		Groups	Number	Character	Type	GMT beginning disturbance		Groups	Number
			h	m					h	m					h	m		
1	0	...	..	..	9	50	0	...	..	..	...	...	0	...	..	..	8	60
2	0	...	..	..	9	35	0	...	..	..	...	...	1	*i*	18	12	10	75
3	0	...	..	..	9	45	0	...	..	..	10	20	1	*i*	..	..	10	90
4	0	...	..	..	10	35	1	*i*	3	10	13	80	0	...	..	..	10	65
5	0	...	..	..	...	...	1	*i*	..	..	12	40	0	...	..	..	11	80
6	1	*i*	21	05	7	20	0	...	..	..	10	55	0	...	..	..	10	90
7	1	*i*	..	..	...	...	0	...	..	..	15	75	1	*i*	22	03	13	110
8	0	...	..	..	8	60	0	...	..	..	15	80	1	*i*	..	..	12	120
9	0	...	..	..	7	50	0	...	..	..	16	85	1	*i*	..	..	11	140
10	0	...	..	..	8	70	0	...	..	..	12	60	0	...	..	..	...	...
11	0	...	..	..	7	60	2	*i*	15	55	11	85	1	...	..	..	...	...
12	0	...	..	..	...	...	2	*i*	..	..	11	75	1	...	17	56	11	110
13	1	*p*	8	35	...	...	1	*i*	.	.	11	80	1	*i*	..	..	11	175
14	1	*p*	..	..	8	135	1	*i*	9	49	13	85	1	*i*	..	..	11	185
15	1	*p*	..	..	10	170	1	*i*	..	..	11	65	0	...	..	..	9	155
16	2	*i*	5	47	9	125	1	*i*	3	50	...	...	0	...	..	..	10	78
17	1	*i*	..	..	8	200	1	*i*	..	..	...	...	0	...	..	..	9*	60
18	1	*i*	..	..	9	170	0	...	..	..	9	40	0	...	..	..	4*	75
19	0	...	..	..	9	185	0	...	..	..	...	...	0	...	..	..	...	...
20	0	...	..	..	8	155	0	...	..	..	10	50	0	...	..	..	7*	75*
21	0	...	..	..	6	76	0	...	..	..	9	60	0	...	..	..	8	75
22	1	*i*	17	15	9	65	0	...	..	..	12	75	0	...	..	..	7	105
23	1	*i*	..	..	10	45	0	...	..	..	13	125	0	...	..	..	6	80
24	1	*i*	..	..	...	...	1	*i*	10	10	10	190	0	...	..	..	6	75
25	0	...	..	..	...	...	0	...	..	..	12	125	0	...	..	..	6	70
26	0	...	..	..	9	55	0	...	..	..	...	...	0	...	..	..	8	80
27	0	...	..	..	11	70	0	...	..	..	11	90	0	...	..	..	11	85
28	0	...	..	..	12	80	1	...	..	..	8	60	0	...	..	..	10	75
29	0	...	..	..	...	...	1	*i*	6	00	10	60	0	...	..	..	12*	120
30	0	...	..	..	...	...	0	...	..	..	9	45	0	...	..	..	8	170
31							0	...	..	..	8	65						
Mean	0.4	...	..	..	...	...	0.5	...	..	..	...	...	0.3			..		

*Revision of value originally broadcast.

Greenwich mean time for ending of storms: 06^{h}, April 7; 24^{h}, April 15; 16^{h}, April 16; $04^{h}\ 35^{m}$, April 24; 05^{h}, May 5; $00^{h}\ 30^{m}$, May 12; 06^{h}, May 15; 09^{h}, May 17; 24^{h}, May 24; 24^{h}, May 29; 03^{h}, June 3; 09^{h}, June 9; $02^{h}\ 20^{m}$, June 14.

Wilson was 0.53 during 1936; during 1937 this value varied from 0.47 to 0.66 with an average value of 0.53.

Mount Wilson Observatory is now supplying corrections and additions to the sunspot-data which are broadcast in the *URSI*gram. So far as possible, these additional and corrected values will be used in this tabular summary and will be designated as such in foot-notes to the Table.

Beginning January 1, 1934, the magnetic information of the *URSI*-gram is for Cheltenham, Maryland, instead of Tucson, Arizona. In addition to this change in observatory, beginning November 1, 1937, the data cover the 24 hours of the Greenwich day ending at 19^h, 75° west meridian mean time instead of the 24 hours ending at 8^h, 75° west meridian mean time.

In accordance with information received from Dr. C. G. Abbot, Secretary of the Smithsonian Institution, on March 6, 1937, solar-constant values were discontinued owing to important change in methods.

The data for the table of Kennelly-Heaviside Layer heights which is self-explanatory are supplied by the National Bureau of Standards.

As set forth in this JOURNAL for June, 1937, "The Department of Terrestrial Magnetism and United States Coast and Geodetic Survey with the coperation of the United States Army and United States Navy communication-services and several amateur radio stations have undertaken to supply the American character-figure based upon the reports of the seven American-operated observatories those of the Department of Terrestrial Magnetism at Huancayo in Peru and at Watheroo in Western Australia, and those of the United States Coast and Geodetic Survey at Cheltenham (Maryland), Honolulu (Hawaii), San Juan (Puerto Rico), Sitka (Alaska), and Tucson (Arizona)." This character-figure is being designated C_A, and the values for May to July, 1938, are given in the accompanying Table.

H. F. JOHNSTON

DEPARTMENT OF TERRESTRIAL MAGNETISM,
CARNEGIE INSTITUTION OF WASHINGTON,
Washington, D. C.

PROVISIONAL SOLAR AND MAGNETIC CHARACTER-FIGURES, MOUNT WILSON OBSERVATORY, APRIL, MAY, AND JUNE, 1938

Greenwich civil time						Range Hor. int.
Beginning			Ending			
1938	*h*	*m*	*d*	*h*	*m*	γ
Apr. 13	11	43*	15	2	..	203
16	5	47*	16	18	..	?
May 11	15	55	12	9		321
June 7	22	02	9	9	..	102
12	17	56	14	2	..	96

*Sudden commencement.

Three active sunspot-groups were all within 30° of the Sun's central meridian when the storm of April 13 began. During the very great storm of April 16 these three groups were still visible, and in addition two more

Day	April 1938								May 1938								June 1938							
	K_2		$H\alpha B$		$H\alpha D$		No. groups	Mag'c char.	K_2		$H\alpha B$		$H\alpha D$		No. groups	Mag'c char.	K_2		$H\alpha B$		$H\alpha D$		No. groups	Mag'c char
	A	B	A	B	A	B			A	B	A	B	A	B			A	B	A	B	A	B		
1	3	3	3	3	2	2	9	0	...	...	...	...	...	...	...	0	3	2	3	2	2	2	8	0
2	3	3	3	3[d]	4	3	9[g]	0	...	...	...	...	...	...	...	0	3	2	3	2	3	2	10[j]	0.5
3	3	3	3[c]	3	4	1	9	0	3	3	4	3	2	1	10[h]	0.5	3	2	3	2	3	3	10[e]	0
4	3	3	3	3	3	1	10	0	3	3	4	3	2	1	13[b]	1	3	3	3	3	2	2	10	0
5	...	...	...	...	...	...	8	0	4	3	4	3	3	2	12	0.5	3	3	3	3	3	2	11	0
6	4	4	...	...	...	...	7	0.5	4	3	4	3[d]	3	3	10[k]	0.5	3	3	3	3	3	1	10	0
7	4	4	...	...	...	...	9	0.5	4	3	4	3	3	3	15[b]	0	3	3	3	3	3	2	13	0.5
8	4	4	4	4[d]	5	3	8	0	4	3	4	3[d]	3	3	15	0	3	3	3	3	4	2	12	1
9	4	4	4	4	4	2	7	0	5	4	4[c]	3[d]	3	1	16[j]	0	3	3	3	3	3	4	11	0.5
10	4	3	4	3	3	3	8	0	5	3	4	3	3	2	12[e]	0	...	...	...	...	...	...	...	0
11	4	2	4	2	4	4	7[e]	0.5	4	4	4	3[d]	4	4	11	2	...	...	...	...	...	...	...[g]	0
12	...	...	...	...	...	...	...	0.5	4	3	4	3	3	2	11	1.5	...	...	...	...	...	...	11	1
13	...	...	...	...	...	...	...	1.5	4	3	4	3	3	2	11'	0	3	2	3	2	3	3	11	1
14	...	...	...	...	...	...	8[k]	1.5	4	3	3	3	3	2	13	1	3	2	3	2	3	3	11	0.5
15	4	3	4	3	3	3	10	0.5	3	3	3	3	3	3	11	0.5	3	2	3	3	2	2	9	0
16	4	3	3	3	3	2	9[e, h]	2	...	...	...	...	...	...	...	0.5	3	3	...	...	...	...	10	0
17	3	3	3	3[d]	4	4	8	0	...	...	...	...	...	...	...[f]	0.5	3	3	3	3	2	2	9	0
18	3	2	...	...	...	...	9	0.5	3	3	3	3	3	3	9	0.5	3	4	3	3	2	2	4	0
19	3	3	3	2	3	3	9	0	...	...	...	...	...	...	...	0	...	...	...	...	...	...	5[e]	...
20	3	3	3[c]	3[d]	3	1	8	0	3	4	3	3	3	3	10	0	...	...	...	...	...	...	7	0
21	3	3	3	3	2	2	6[f]	0	3	3	3[c]	3	3	3	9[g]	0	...	...	...	...	...	...	8[a]	0.5
22	3	4	3	4	2	1	9[f]	0.5	3	3	4	3	3	4	12[a]	0	3	4	3	4	3	2	7[e, h]	0
23	3	4	...[c]	...	...	...	10[b]	1	4	4	4[c]	4	3	1	13[g]	0	2	3	3	3	3	2	6	0
24	...	...	...	...	...	...	...	0.5	...	...	...[c]	...	...	...	10[h]	...	3	2	3	2	4	3	6	0
25	...	...	...	...	...	...	...	0.5	4	3	...	...	...	...	12	0.5	3	2	3	2	4	3	6	0
26	3	2	3	1	2	2	9	0	...	...	...	...	...	...	12[a]	0	3	2	3	1	4	1	8	0
27	3	3	3	3	3	2	11	0	4	3	...	...	...	...	11	0	3	3	3	3	4	1	11[b]	0
28	...	...	...	...	...	...	12[g]	0	4	3	4?	3?	4?	3?	8	0.5	3	3	3	3	4	1	10	0
29	...	...	...	...	...	...	...	0	4	4	4	4	4	3	10[b]	0.5	3	3	3	3	4	2	12	0
30	...	...	...	...	...	...	...	0	3	4	3	4[d]	3	2	9	0	4	4	4	4	3	2	8	0
31									4	3	4	3	2	1	8	0								
Mean	3.4	3.1	3.3	2.9	3.2	2.3	8.7	0.4	3.8	3.2	3.7	3.1	3.0	2.4	11.3	0.4	3.0	2.8	3.0	2.7	3.1	2.1	9.1	0.2

NOTE—For an explanation of these tables see this JOURNAL, 35, 47-49 (1930).

?Indicates an uncertain value which should be given low weight.

The character-figures of solar phenomena are estimated from the spectroheliograms which are made with a 2-inch solar image, usually in the early morning. The very bright chromospheric eruptions are reported in these notes if observed at any time during the day.

a, b Formation of a new group which later developed to average size or larger; (a) less than 30° from the center of the disk, (b) more than 30° from the center of the disk.

... (c) less than 30° from the center of the disk, (d) more than 30° from the center of the disk ... respectively.

active groups had appeared at the Sun's east limb A bright aurora was visible at Mount Wilson near midnight of April 16 (8^h, GMT). The motion of the H-element was so violent that the maximum was off the sheet and the minimum was indistinguishable, making it impossible to measure its range.

The intense magnetic storm of May 11 was probably due to activity associated with the spot-group which crossed the central meridian on May 10.4, 4° from the center of the solar disk. This group returned twice, crossing the central meridian on June 6.3 and July 3.2, respectively. At each of these returns moderate magnetic storms began about a day and a half after the central meridian passage of the group. The three magnetic storms associated with this group began at May 11.7, June 7.9, and July 4.5, the corresponding intervals after its central meridian passage being 1.3, 1.6, and 1.3 days, respectively. These magnetic storms are part of a sequence of disturbances that has persisted since the beginning of 1937.

A very bright chromospheric eruption was observed on May 11 from $15^h 03^m$ to $15^h 42^m$, GMT, near a group in latitude 26° south and longitude 36° east. Nevertheless, in view of the sequence of which the storm of May 11 appears to be a member, it seems probable that it was associated with the group previously mentioned rather than with this bright chromospheric eruption which occurred near the beginning of the storm.

CARNEGIE INSTITUTION OF WASHINGTON,
MOUNT WILSON OBSERVATORY,
Pasadena, California

SETH B. NICHOLSON
ELIZABETH E. S. MULDERS

SOVIET POLAR MAGNETIC OBSERVATORIES

The Union of Socialistic Soviet Republics is in an especially favorable situation for securing magnetic and other geophysical observations in the polar regions since it possesses an unusually great extent of territory lying within the Arctic Circle. That this opportunity is not being neglected is apparent from the fact that there are at present no less than five permanent polar magnetic observatories in the U.S.S.R., operated by the Central Administration of the Northern Sea Route, namely, Matochkin Shar, Calm Bay, Dickson, Cheliuskin, and Wellen. The establishment of these observatories took place at different times and under different conditions and hence they are not uniform as regards methods and arrangements for work. The aim of the Central Administration is the unification of these observatories and the modification of their conditions so that, in addition to the normal observatory-work, researches in terrestrial magnetism and related fields may be undertaken.

The following data regarding the present Soviet polar stations are taken from the "Information Book on Terrestrial Magnetism and Electricity," No. 4, 1937, published by the Central Geophysical Observatory.

Matochkin Shar ($\phi = 73° 16'$ north, $\lambda = 56° 24'$ east) is the oldest of the five polar magnetic stations, having been founded in 1923. Up to 1926 the observations were carried out in two unheated buildings—the absolute and variation buildings. In 1926 the variation building was heated and in it was installed a second set of self-recording instruments, which functioned until 1931. A better-suited variation building was

completed in 1938. At present there is in operation one set of self-recording Eschenhagen instruments. For the absolute observations a Bamberg theodolite with inclinometer is used.

In addition to the magnetic observations, measurements of earth-currents (since 1936) and observations of polar lights are made. Besides the regular visual observations, the intensity of the aurora is also recorded by instrumental means.

Calm Bay ($\phi = 80° 20'$ north, $\lambda = 52° 43'$ east) is next to the oldest observatory in the Soviet Arctic, having been organized in 1931. The building used for both variation and absolute observations is heated. A set of self-recording Eschenhagen instruments has served as variometers from the establishment of the Observatory until the present time. Absolute observations during the first winter were made with an Eschenhagen universal instrument but, since 1932, with a new absolute Bamberg theodolite.

Dickson ($\phi = 73° 30'$ north, $\lambda = 80° 25'$ east) was opened in November 1932. The building for absolute and variation observations is heated. From the establishment of the Observatory until the present time, a self-recording Eschenhagen set has served for recording the variations. For absolute observations there is used an Edelmann universal theodolite, which should be replaced as soon as possible owing to its unsatisfactory condition.

Wellen ($\phi = 66° 10'$ north, $\lambda = 190° 80'$ east) was established in 1933. The building which is used for both absolute and variation observations is not wholly suitable, needing repairs, the completion of which is expected in 1938. As magnetograph a quick-run la Cour magnetograph was operated during the first winter, the recording drum rotating once every two hours. The next winter the la Cour instrument was replaced by one of the standard Eschenhagen type. Absolute determinations have always been made with an Ogloblinsky instrument.

Cheliuskin ($\phi = 77° 43'$ north, $\lambda = 104° 17'$ east) began operation January 1, 1935. A heated building served for both absolute and variation observations. A standard la Cour magnetograph is in operation and a Bamberg theodolite serves for the absolute observations.

All these observatories are provided with chronometers. In addition to the magnetic observations visual observations of the aurora are systematically made which, in view of the paucity of auroral data in these regions, should be extremely valuable.

The observatories came under the control of the Central Administration of the Northern Sea Route in 1933. The magnetic data are reduced at the Section of Terrestrial Magnetism of the Arctic Institute, which by the end of 1937 had completed the reduction of the material from Dickson, Calm Bay, Wellen, and Cheliuskin for 1935.

During 1935-36 magnetic observations were made along the Kolyma River, at 54 stations between Srednekan and Ambarchik Bay and at 25 stations along the route between Nogaevo and Srednekan. In order to provide corrections on account of the variations of the Earth's magnetic field, a temporary variation-station was built at the mouth of the Srednekan ($\phi = 62° 26'.4$ north, $\lambda = 152° 18'.8$ east) and was equipped with variometers of the Yanovsky system and a Wild-Edelmann universal theodolite. At the close of the survey-work, it is proposed to

attach this station to the Kolyma Geophysical Observatory as a permanent Magnetic Section.

H. D. HARRADON

DEPARTMENT OF TERRESTRIAL MAGNETISM,
CARNEGIE INSTITUTION OF WASHINGTON,
Washington, D. C.

PRELIMINARY RESULTS OF MAGNETIC MEASUREMENTS AT THE "NORTH POLE" STATION*

We took magnetic measurements with the aid of a theodolite and also diurnal series of measurements of the magnetic variations using special visual magnetometers. A total of 55 measurements of declination and of horizontal intensity and 36 measurements of inclination were made.

Up to the middle of November, 1937, 14 diurnal series of measurements of variation were made, but later the ice-floe began to turn around hindering the use of the variometers. As a result of measurement of the

TABLE 1—*Preliminary summary of magnetic measurements, "North Pole" Station, 1937*

Group	Latitude, north		Longitude, east		Declination, west	Horizontal intensity	Inclination, north	
	°	′	°	′	°	γ	°	′
1	89	25	305		40	314	86	36
2	88	54	343		37	335	86	23
3	88	51	359		41	357	86	19
4	88	30	348		38	355	86	10
5	88	15	356		35	393	85	54
6	87	59	357		32	389	85	56
7	87	10	002		31	430	85	44
8	86	39	359		27	452	85	19
9	85	58	001		28	474	84	57
10	85	40	001		26	499	84	47
11	85	08	006		24	516	84	29
12	84	37	003	42	26	534	84	20
13	84	07	003	00	24	567	83	57
14	83	47	357	30	26	641	83	12
15	82	57	354	20	23	613	83	18
16	82	27	353	10	19	612	83	10
17	81	51	352	59	21	643	82	55
18	81	02	353	10	20	667	82	26
19	80	00	353	05	20	727	81	58
20	79	36	352	43	19	732	81	55
21	78	58	350	57	18	744	81	45
22	78	16	349	40	17	774	81	28
23	77	46	347	55	15	783	81	17
24	77	17	347	35	13	809	80	46
25	76	38	346	25	10	797	81	12
26	76	29	346	25	13	800	.	.
27	71	50	339	45	..	968		..

*Translation by courtesy of C. Oumansky, Chargé d'Affaires, Embassy of U.S.S.R., Washington, D. C.

variations it was observed that the declination had an average diurnal value at about 6^h, 13^h, and 0^h, GMT; between 6^h and 13^h the deviation was to the east, between 13^h and 0^h to the west, and between 0^h and 6^h a little to the east; these characteristics persisted in all cases. The amplitude ranged from 2° on quiet days to 10° on disturbed days. The horizontal intensity had an average diurnal value at about 6^h, 10^h, and 18^h; a small maximum was observed from 6^h to 10^h, a large minimum from 10^h to 18^h, and a large maximum from 18^h to 6^h. In the main this character persisted. The amplitude ranged from 150 to 500 gammas.

During changes in the variations readings were made every two minutes during 40 minutes of every hour for 24 hours. The diurnal course indicated above is based on the course of the average values of these 40-minute intervals. In Table 1, which gives geographic distribution, all values are reduced to the average mean position for the day, using the actual daily course; only through such an operation may the spatial distribution prove sufficiently smooth. The results of the measurement are averaged for 27 points.

Prior to September 1, 1937, three diurnal series were taken for measurement of the atmospheric-potential gradient during days with little cloudiness. The average value was about 110 volts per meter, the maximum about 200, the minimum 40. The diurnal course was of the oceanic type with maximum about 18^h GMT, minimum about 0^h, and amplitude about 100 volts.

E. FEDOROV

PRINCIPAL MAGNETIC STORMS

SITKA MAGNETIC OBSERVATORY

APRIL TO JUNE, 1938

(Latitude 57° 03′.0 N., longitude 135° 20′.1 or $9^h 01^m.3$ W. of Gr.)

April 13-15—A moderate magnetic storm began gradually at about $11^h 42^m$ GMT, April 13, with an increase in the horizontal intensity and decreases in the vertical intensity and east declination. The storminess gradually increased with short-period vibrations superimposed on a long-period motion. At $05^h 26^m$, April 14, there was a sudden decrease in the horizontal intensity of 600 gammas accompanied by similar changes in the vertical intensity and declination. After 09^h, April 14, the storm gradually subsided; the traces reaching normal values at 04^h, April 15. Ranges: D, 102′; H, 1285 gammas; Z, 371 gammas.

April 16-18—A major storm began abruptly at $05^h 47^m$ GMT, April 16, and continued very disturbed until about 16^h, April 16. This storm was unusual in that the normally calm interval after the abrupt commencement was absent. The storm was characterized by the usual rapid vibrations with large amplitudes. The elements remained moderately disturbed until about 20^h, April 18. This storm was accompanied by a brilliant auroral display visible throughout this region. Radio communication was completely interrupted. Ranges: D, 290′; H, 2210 gammas; Z, 991 gammas.

May 11-13—A moderate magnetic storm began abruptly at $15^h 53^m$ GMT, May 11, with a sudden movement of the three elements. The motion was rapid and of short period during the first few hours of the storm and thereafter consisted of large bays with superimposed short-period vibrations. The storm ended at 02^h, May 13. Ranges: D, 94′; H, 1017 gammas; Z, 652 gammas.

May 14-15—A minor storm began gradually at 03^h GMT, May 14. At 10^h the activity increased sharply with rapid vibrations of the three elements until 15^h. Thereafter the storm gradually subsided and ended about 06^h, May 15. The three elements however remained moderately disturbed for several days. Ranges: D, 110′; H, 964 gammas; Z, 659 gammas.

ROBERT E. GEBHARDT, *Observer-in-Charge*

CHELTENHAM MAGNETIC OBSERVATORY

APRIL TO JUNE, 1938

(Latitude 38° 44′.0 N., longitude 76° 50′.5 or $5^h 07^m.4$ W. of Gr.)

April 13-15—A moderate disturbance began at $08^h 40^m$ GMT, April 13, and continued until 02^h, April 15. The storm was characterized by great short-period activity of not very large range. Ranges: H, 188 gammas; Z, 178 gammas; D, 30′.

April 16—A great storm began abruptly at $05^h 47^m$ GMT, April 16. For four hours thereafter the activity was very great with extremely large ranges in all the elements. During the first 40 minutes of the storm

the movements of *H* were so rapid that no registration of the light-spot took place on either of the two magnetographs. During this interval the maximum of *H* occurred beyond the limits of the magnetograms. The total range of *H* was more than 1123 gammas. The first hour after the commencement of the storm *Z* fell slowly, then during the next two hours fell rapidly to its minimum value and returned to normal value. The entire range of 1021 gammas in *Z* was below the normal value of that element. *D* first decreased about one-fourth degree then increased in about one and one-half hours to its maximum value, after which it decreased in about 40 minutes to its minimum value. The range in *D* was 4° 51′. The storm ended at 16^h, April 16.

May 4—A mild storm began at 12^h GMT, May 4, and ended at midnight of the same day. The perturbations were chiefly of short period. The outstanding feature of the storm was a downward peak in *H* between 15^h and 16^h. In that hour *H* decreased 110 gammas and then increased 175 gammas. Ranges: *D*, 34′; *H*, 222 gammas; *Z*, 62 gammas.

May 11-13—A severe storm began at $15^h\ 55^m$ GMT, May 11. In the first three hours the fluctuations were moderate; then *H* and *Z* began to increase rapidly and during the 22nd hour of May 11 both *H* and *Z* had very high values. The fluctuations in all three elements were very rapid and large from 21^h, May 11, to $00^h\ 30^m$, May 12. The storm gradually subsided after 01^h, May 12, and ended at 02^h, May 13. Ranges: *D*, 86′; *H*, 700 gammas; and *Z*, 789 gammas.

May 14-15—A mild storm began at $09^h\ 49^m$ GMT, May 14, and ended at 06^h, May 15. The perturbations were irregular. Ranges: *D*, 31′; *H*, 150 gammas; *Z*, 94 gammas.

June 7-9—A mild storm beginning suddenly at $22^h\ 03^m$ GMT, June 7, continued until 09^h, June 9. Ranges: *D*, 20′; *H*, 155 gammas; *Z*, 53 gammas.

June 12-14—Beginning abruptly at $17^h\ 56^m$ GMT, June 12, *H* decreased 17 gammas and then as suddenly increased 72 gammas. West declination increased 1′.5 followed by a decrease of 6′. *Z* changed abruptly a small amount. Between $23^h\ 40^m$ and 24^h rapid changes again occurred. The storm was not very great and it ended at $02^h\ 20^m$, June 14. Ranges: *D*, 32′; *H*, 192 gammas; *Z*, 68 gammas.

ALBERT K. LUDY, *Observer-in-Charge*

TUCSON MAGNETIC OBSERVATORY

APRIL TO JUNE, 1938

(*Latitude 32° 14′.8 N., longitude 110° 50′.1 or $7^h\ 23^m.3$ W. of Gr.*)

April 13-15—A moderate storm began sharply at $11^h\ 41^m$ GMT, April 13, with a sudden increase in *H* of 81 gammas, followed immediately by a decrease of 56 gammas. Numerous similar quick thrusts in *H* were the chief characteristic of the storm, which lasted until about 01^h, April 15. *H* was somewhat depressed during part of the period, but not greatly at any time.

April 16—A severe but short-lived disturbance began at $05^h\ 47^m$ GMT, April 16. *H* increased 185 gammas in about one minute; then, after hesitating about a quarter-hour, the element increased even more rapidly, the spot going off the sheet on the side for which no reserve-spot

is provided. The edge of the sheet corresponded to a value of 26676 gammas, or about 475 gammas above normal for that part of the day. After another quarter-hour the spot came back on the sheet and continued moving downward so rapidly that in a little less than an hour and a half it reached the low point of the storm, 810 gammas lower than when it came back on the sheet. D and Z were considerably disturbed, D fluctuating through a range of 47′. After the storm had lasted about two hours the activity began to diminish, and twelve hours after the beginning the elements were quiet again, though H remained low for more than a day longer.

May 11-12—A moderately severe storm began about 16^h GMT, May 11, and ended, except for a low value of H, about 10^h, May 12. The first half of the period was the more severely disturbed, and, as usual, the activity was concentrated largely in H. The range in this element was 325 gammas. The ranges in D and Z were 27′ and 115 gammas, respectively.

June 7-9—A very moderate disturbance began sharply at $22^h\,02^m$ GMT, June 7, with an increase in H of 48 gammas. Thereafter until 09^h, June 9, the traces were moderately disturbed.

June 12-14—A disturbance of about the same intensity as that of June 7-9 began about 18^h, June 12, and lasted until about 02^h, June 14. Several movements of D and Z, though small, were sharper in comparison to the movement in H than is usual.

John Hershberger, *Observer-in-Charge*

Huancayo Magnetic Observatory

April to June, 1938

(*Latitude 12° 02′.7 S., longitude 75° 20′.4 or $5^h\,01^m.4$ W. of Gr.*)

April 6—A sudden commencement of small amplitude occurred at $21^h\,05^m$ GMT, April 6. In a period of four minutes, H decreased 5 gammas and increased 42 gammas; Z increased 5 gammas and D moved westward less than 1′.0. Following this the traces were only slightly disturbed.

April 11—A sudden commencement of small amplitude occurred at $10^h\,32^m$ GMT, April 11. In a period of one minute, H increased 13 gammas; Z increased 2 gammas and D showed only a very slight effect. The traces were moderately disturbed until 20^h.

April 12—At $19^h\,58^m$ GMT, April 12, a sharp peak was recorded in H. In nine minutes H increased 88 gammas. In the same interval Z increased 14 gammas and D moved 0′.5 eastward. This occurred on an otherwise quiet day.

April 13-14—A sudden commencement occurred at $11^h\,42^m$ GMT, April 13. H increased 48 gammas; Z increased 12 gammas and D moved eastward 1′.0 and then westward 1′.0 during an interval of three minutes. Following this a moderate disturbance continued until the end of April 14. It was characterized by a large number of rapid oscillations of relatively small amplitude. Ranges: D, 8′.9; H, 420 gammas; Z, 46 gammas.

April 16—The most intense disturbance yet recorded at this Observatory began with a sudden commencemnt at $05^h\,47^m$ GMT, April 16 In an interval of one minute, H increased 179 gammas; Z increased 24

gammas and D moved westward 2′.4. The traces were very disturbed until $08^h\ 30^m$, after which a moderate disturbance continued until 17^h. The high sensitivity H-trace was not legible during the first and more violent part of this storm. Ranges: D, 25′.4; H, 1321 gammas; Z, 118 gammas.

April 23-24—A moderate disturbance occurred from 11^h GMT, April 23, to 3^h, April 24.

May 4—A moderate disturbance occurred from 14^h to 20^h GMT, in which a number of fluctuations were recorded in H.

May 11-13—A magnetic storm began with a sudden commencement at $15^h\ 55^m$ GMT, May 11. In a period of three minutes H decreased 4 gammas and increased 103 gammas; D moved eastward 2′.0 and Z increased 8 gammas. Rapid fluctuations of large amplitude occurred in H from the commencemt until $00^h\ 30^m$, May 12, followed by lesser disturbances until 02^h, May 13. The value of H from $18^h\ 30^m$, May 11, until the end of the storm, was very low. Ranges: D, 10′.2; H, 837 gammas; Z, 73 gammas.

May 14-15—A moderate disturbance occurred from 12^h GMT, May 14, to 02^h, May 15.

May 24—At $12^h\ 55^m$ GMT, May 24, a sudden commencement of small amplitude occurred. In three minutes H increased 20 gammas, D moved eastward 1′.0 and a very slight increase occurred in Z. Following this a moderate disturbance continued until 20^h.

May 29—A moderate disturbance occurred from 06^h to 20^h GMT, during which a number of fluctuations were recorded in H.

June 7-8—At $22^h\ 02^m$ GMT, June 7, a sudden commencement occurred in all elements. During an interval of four minutes H increased 65 gammas; Z increased 12 gammas, and D moved west 0′.7. Following this the traces were moderately disturbed until 23^h, June 8. From 12^h-22^h, June 8, the H-trace showed a number of fluctuations of moderate amplitude.

June 12—At $17^h\ 55^m$ GMT, June 12, a sudden commencement occurred in all elements. During a period of four minutes H decreased 6 gammas and then increased 97 gammas; Z increased 8 gammas; and D moved west 0′.6, then returning to its previous position.

June 12—At $23^h\ 40^m$ GMT, June 12, a sudden commencement occurred. In four minutes H increased 52 gammas; Z increased 8 gammas; and only a very slight effect occurred in D. Following this the traces were only slightly disturbed.

FRANK T. DAVIES, *Observer-in-Charge*

APIA OBSERVATORY

APRIL TO JUNE, 1938

(*Latitude 13° 48′.4 S., longitude 171° 46′.5 or $11^h\ 27^m.1$ W. of Gr.*)

April 13-15—At $11^h\ 42^m$ GMT, April 13, a sudden increase of 34 gammas in H marked the beginning of a disturbed period which lasted until early on April 15. The range in H was 161 gammas.

April 16-17—A major disturbance commenced at $05^h\ 47^m$ GMT, April 16, with a sharp rise in H of 100 gammas and in Z of 27 gammas. The maximum in H occurred at $06^h\ 24^m$ and the minimum at $09^h\ 29^m$; the

range in H being 474 gammas. In Z the maximum occurred at $06^h\ 13^m$ and the minimum at $08^h\ 09^m$ with a range of 106 gammas. There were rapid small oscillations in D during the phase of maximum activity. The trace had returned to normal by April 18.

May 11—A sudden small increase in the H-ordinate at $15^h\ 54^m$ GMT, May 11, was the commencement of a short disturbance. The H-clock stopped and thus the variations in this element were lost but rapid oscillations in Z continued until early on May 12.

June 7—A slight disturbance commenced at $22^h\ 03^m$ GMT, June 7, with an abrupt increase in H of 39 gammas. There were corresponding increments in Z.

June 12—Slight fluctuations in H commenced with a sudden increase of 24 gammas at $23^h\ 40^m$ GMT, June 12. Z was similarly affected. The D-trace was affected only very slightly.

J. Wadsworth, *Director*

Watheroo Magnetic Observatory

April to June, 1938

Latitude 30° 19′.1 S., longitude 115° 52′.6 or $7^h\ 43^m.5$ E. of Gr.)

April 13-14—Following a sudden commencement at $11^h\ 43^m$ GMT, April 13, D moved westerly 0′.5 suddenly, then 1′.5 in forty seconds and 5′ during the next three minutes. H increased 27 gammas in three minutes followed by an abrupt decrease of 10 gammas and a further increase of 15 gammas. The numerical value of Z after an initial increase of 2 gammas decreased 8 gammas abruptly followed by an increase of 20 gammas in three minutes. Disturbed conditions prevailed for 24 hours.

April 16—This storm began as a sudden commencement at $05^h\ 47^m$ GMT, April 16, but the record is unreadable on account of rapidity of motion. Scalings are very uncertain for seventh and eighth hours. Apparently H-spot went off the trace at $05^h\ 50^m$, and hence the tabulated range in H is approximate. The storm ceased at 20^h. Ranges: D, 38′; H, 413 gammas; Z, 235 gammas.

June 7-8—There was a sudden commencement at $22^h\ 03^m$ GMT, June 7. D moved westerly nearly 1′ abruptly, then easterly 5′ in two minutes and then westerly 4′ in five minutes. H increased 26 gammas in two minutes remaining high and slightly disturbed. The numerical value of Z increased 3 gammas abruptly then decreased 28 gammas in two minutes followed by an increase of 12 gammas in four minutes. The traces were lightly disturbed for 24 hours.

June 12-13—There was a sudden commencement at $17^h\ 55^m$ GMT, June 12. D moved westerly 0′.5 abruptly, then easterly 3′ in two minutes. H increased 20 gammas in three minutes. The numerical value of Z increased 3 gammas abruptly then decreased 17 gammas in three minutes. There was a moderately strong disturbance during the next 24 hours.

J. W. Green, *Observer-in-Charge*

NOTES

(See also pages 226 and 244)

35. *Personalia*—Dr. *L. B. Snoddy*, of the University of Virginia, will spend part of the summer this year at Chesterfield or Churchill, Canada, making special auroral investigations. In these studies he will use a special photometric equipment which he has designed for the purpose. Mrs. Snoddy will accompany him.

Dr. *Gustav Swoboda*, of the Meteorological Institute of the Czechoslovak Republic, Prague, Czechoslovakia, has been appointed to succeed Dr. *Cannegieter*, who assumed his new duties as Director-in-Chief of the Royal Meteorological Institute of the Netherlands.

Commander *Otis W. Swainson*, who was previously in charge of the office of the United States Coast and Geodetic Survey at Seattle, Washington, and more recently in command of the Steamer *Guide*, has been transferred to succeed Lieutenant-Commander *E. W. Eickelberg*, Assistant Chief of the Division of Terrestrial Magnetism and Seismology of the Survey at Washington, D. C. Lieutenant-Commander Eickelberg will assume command of the Steamer *Guide*, with base at San Francisco.

Dr. *Boleslaw Cynk* of the Gdynia Marine Observatory, Gdynia, Poland, is spending about three months at the Department of Terrestrial Magnetism this summer familiarizing himself with the Department's technique and methods of making geomagnetic and atmospheric-electric observations.

Dr. *Vannevar Bush*, vice-president and dean of engineering of the Massachusetts Institute of Technology, was elected on June 2, 1938, President of the Carnegie Institution of Washington, the appointment to take effect January 1, 1939. He succeeds Dr. *John C. Merriam*, who was elected President in 1921 and will become President Emeritus. Dr. *Edward L. Moreland* has been appointed dean of engineering at the Massachusetts Institute of Technology.

Dr. *Ralph Howard Fowler*, Plummer Professor of Applied Mathematics in the University of Cambridge, has been appointed Director of the British National Physics Laboratory. Dr. Fowler will succeed Dr. *W. L. Bragg*, who has been elected Cavendish Professor of Experimental Physics in the University of Cambridge.

The list of Birthday Honors conferred by King George VI this year includes the name of Dr. *S. K. Mitra*, Professor of Physics, University of Calcutta, well known for his work on cosmic rays, on whom the Order of the British Empire was conferred.

The honorary degree of doctor of engineering was conferred June 17, 1938, by the Worcester Polytechnic Institute on *Arthur D. Butterfield*, Professor of Geodesy at the University of Vermont.

Professor Dr. *Hugo Hergesell*, for many years director of the Aeronautical Observatory, Lindenberg, and well known for his activities in the International Meteorological Organization, died June 6, 1938, aged 79 years.

Dr. *George O. Wiggin*, formerly Director (1915-24) of the Oficina Meteorológica Argentina, died at Buenos Aires, January 10, 1938, aged 68 years.

LIST OF RECENT PUBLICATIONS

BY H. D. HARRADON

A—Terrestrial and Cosmical Magnetism

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B—Terrestrial and Cosmical Electricity

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THE ELECTRIC CURRENT-SYSTEM OF GEOMAGNETIC DISTURBANCE

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I—*Introduction*

I. 1—This paper concerns the electric current-system associated with the main systematic characteristics of geomagnetic disturbance or magnetic storms. The discussion continues that given previously in a sequence of papers by Chapman [see 1, 2, 3 of "References" at end of paper].

The Earth's surface magnetic field may be analysed into parts of origin external and internal to the Earth. The separation of the parts is accomplished by means of a spherical harmonic analysis, using a method originally due to Gauss [4]. The larger part of the *daily variation-field* is caused by sources external to the Earth, while a smaller part (not likely to exceed about 30 per cent of the whole [5], for variations having a period of a day or more) is due to internal causes. Schuster [6] suggested that external atmospheric-electric currents were the cause of the daily variation-field and that they induced less intense electric currents within the Earth. The present study at first neglects the field of internal origin, present in the variation-fields at the Earth's surface; later certain tentative corrections for induced currents are applied.

It has been pointed out that the form and position of the electric current-system flowing above the Earth's surface cannot be inferred uniquely, from a knowledge of the distribution of the disturbance-field at the Earth's surface. Further evidence bearing on its probable position is necessary, such as is afforded by the distribution of the electric conductivity at points above the Earth. For instance, it is probable that if the currents flow in the atmosphere, they do so in one or other of the highly ionized regions, of which the most important are the E-, F_1-, and F_2-regions, at respective heights roughly about 100 km, 180 km, and 250 km above the Earth.

In the present investigation we consider the average features of geomagnetic disturbance, neglecting the irregular part. Alternative theoretical forms of current-systems proposed by Birkeland and by Chapman are examined to check their agreement with observation. These systems will be here respectively designated by the initials B and C. Current-system B flows within the Earth's atmosphere, with an intake and outflow of current from space near the zones of maximum auroral frequency; the polar part of the system C flows entirely within the Earth's atmosphere, upon an approximately spherical surface concentric with the Earth, though in addition there may be a part in the form of a ring-current encircling the Earth at a distance of a few Earth-

radii. The magnetic fields of the systems B and C are compared and their heights for best fit with observation are deduced. Extensive new data for north polar regions are used in the comparisons.

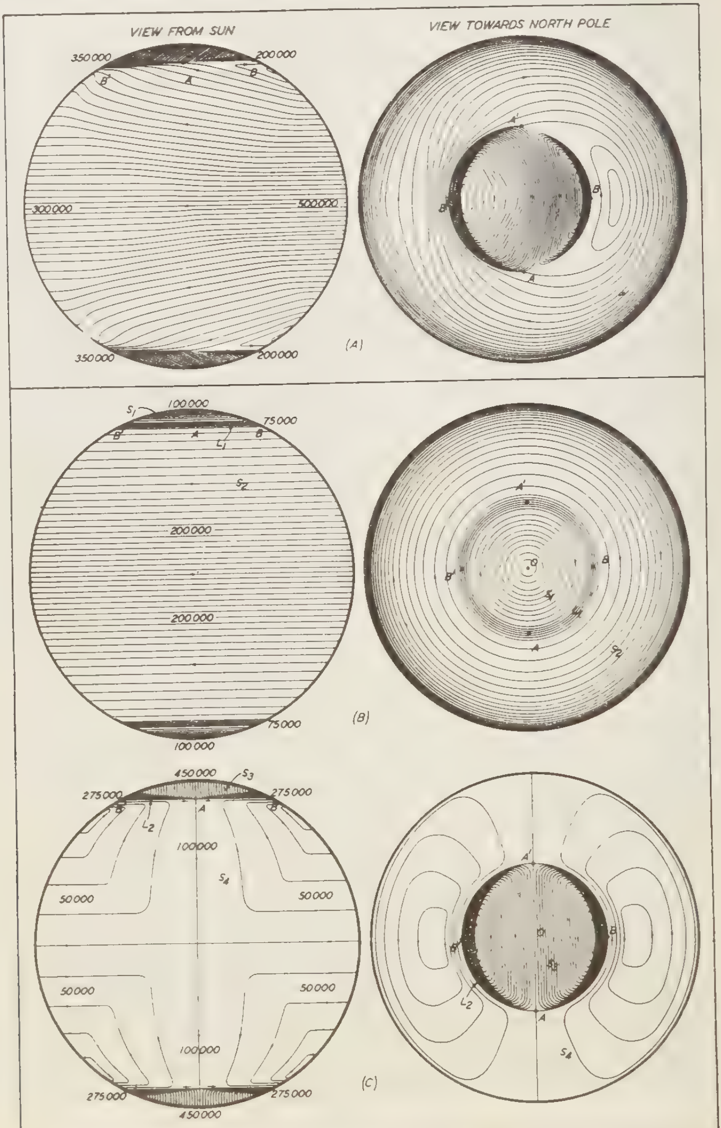

FIG. 1—(A) ELECTRIC CURRENT-SYSTEM OF GEOMAGNETIC DISTURBANCE; (B) AND (C) RESPECTIVELY, PARTIAL CURRENT-SYSTEMS S_D AND D_m COMPRISING (A)

[Note: The last line of title should read "current-systems D_m and S_D".]

In the polar regions the Earth's surface disturbance-field is particularly intense and highly differentiated locally. It is therefore desirable that the fields of the two current-systems be known in these regions in order that they may be compared directly with observation at many points. For this reason the fields due to the current-systems B and C are approximately derived, using analytical methods.

II—*The field of current-system C*

II. 1—We first consider the current-system due to Chapman. It is shown in A of Figure 1, where it is drawn appropriate to a spherical Earth having its geographic and magnetic axes coincident. It is intended to correspond, apart from irregular disturbances, with the geomagnetic variations (or disturbance D) of the Earth's field, additional to those present on magnetically quiet days.

On the left-hand side is shown a view from the Sun for a time of magnetic storm (main phase). On the right a view from above the north pole is represented. The current-system is thus supposed fixed in orientation relative to the Sun, and the Earth revolves within it. A total of 10,000 amperes flows between successive current-lines. The currents are most concentrated along the zones of maximum auroral frequency.

The current-system may be analysed into two partial ones shown in B and C of Figure 1. B of Figure 1 represents that responsible for the storm-time component (D_{st}) of disturbance (it is the non-polar part of this system that is not definitely assigned to the Earth's atmosphere); C of Figure 1 shows the part responsible for the disturbance diurnal variation S_D depending on local time.

The current-systems are idealized patterns, and alter markedly in intensity and to some extent also in form and sign with the time.

II. 2—In the analytical evaluation of the magnetic force we consider the partial current-systems separately. Figure 2 shows schematically a decomposition of the partial current-systems D_m and S_D into idealized component parts. In the case A of Figure 2 we obtain a useful approximation by means of idealization of the model, and considering separately the parts shown in B and C of Figure 2. We suppose the portion $ABA'B'$ flowing near the auroral zone to be concentrated to a uniform circular current-line L_1 (B of Fig. 2), flowing at a constant height above a circular auroral zone; within L_1 flows a uniform spherical-cap current-sheet S_1. These are supposed superposed upon a complete spherical current-sheet S_2 (C of Fig. 2). In S_2 the current flowing between successive planes orthogonal to the Earth's magnetic axis and at unit-distance apart is the same, whatever the positions of these planes. We refer to the partial current-system obtained by superposing B and C of Figure 2 as the idealized current-system D_m, appropriate to the average storm-time variation D_{st}.

In the case of the system S_D (Fig. 2, D), we assume the zonal currents concentrated to a current-line L_2, along the circle $ABA'B'$ (E of Fig. 2). We suppose the strength of current along L_2 varies as the sine of the longitude, being zero in the solar plane AOA', and having its maximum magnitude at the orthogonal plane BOB' passing through the Earth's axis. The current-sheet flowing across the polar cap in the direction towards the Sun, which completes the main part of the current circuit

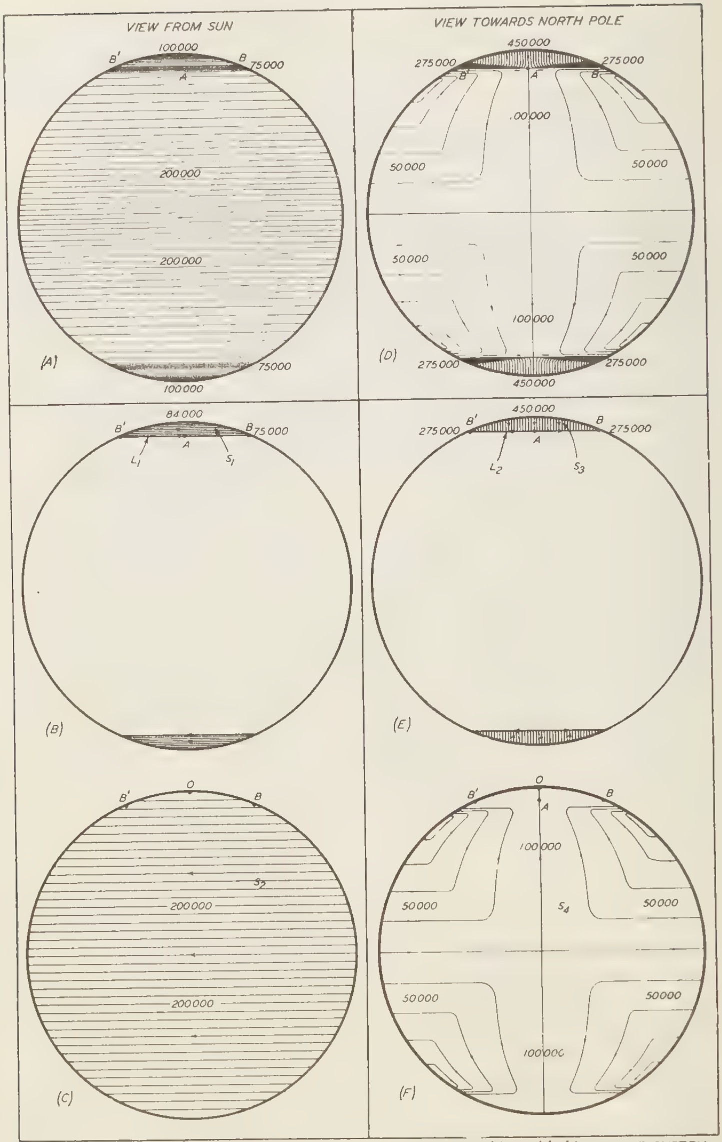

FIG. 2—(A) CURRENT-SYSTEM D_m WITH IDEALIZED COMPONENT PARTS (B) AND (C); (D) CURRENT-SYSTEM S_D WITH IDEALIZED COMPONENT PARTS (E) AND (F)

of L_2, will be denoted by S_3. The currents L_2 and S_3, together with S_4 the dispersed current-system *between* the two auroral zones (F of Fig. 2) make up the whole idealized current-system S_D.

For our purpose it is sufficient to evaluate the fields due to D_m and S_D, for points in high northern latitudes. We therefore neglect the presence of the south polar parts, and the less intense part of D_m and S_D (namely S_2 and S_4) flowing between the two auroral zones. Consequently we leave out of account the parts of the field (in polar regions) that may be due to currents beyond the atmosphere (additional computations are also made for the case when S_2 is taken to flow within the atmosphere). We evaluate the fields for points on the Earth within the noon half-plane $O'AO$, and the evening half-plane $O'BO$, the point O' representing the center of the Earth. These are also the half-planes of symmetry of the current-system S_D.

In these computations the electric currents are supposed constant.

We adopt the following notation:

Vector magnetic forces at any point on the Earth's surface

$\mathbf{S}_D$, $\mathbf{D}_m$ = the force due to the world-wide current-systems S_D and D_m, respectively

$\mathbf{L}_1$ = the force due to the circular current-line L_1 of D_m

$\mathbf{S}_1$ = the force due to the circular spherical-cap current-sheet S_1 of D_m

$\mathbf{S}_2$ = the force due to the spherical current-sheet S_2 of D_m

$\mathbf{L}_2$ = the force due to the circular current-line part of S_D

$\mathbf{S}_3$ = the force due to the spherical-cap current-sheet part of S_D

Current-strengths in electromagnetic units

i_1 = the current-strength of L_1

i'_1 = the current in S_1 crossing perpendicularly above unit-width of the radius of the circle $ABA'B'$

i''_1 = the total current flowing in S_1

i'_2 = the current in S_2 flowing between any two planes orthogonal to the Earth's axis, and at unit-distance apart

i''_2 = the total current flowing in S_2

i_2 = the current-strength of L_2 at the point B

i_3 = the current in S_3 crossing perpendicularly above unit-width of the diameter BB' of the circle $ABA'B'$

i''_3 = the total current flowing in S_3

Also

R = the radius of the spherical surface concentric with the Earth and upon which all currents flow

R' = the radius of the Earth

O' = the center of the Earth

O'' = the center of the circle $ABA'B'$

p = the radius of the circle $ABA'B'$

P = the point on the Earth at which the magnetic force is required

Φ = the magnetic latitude

Λ = the magnetic longitude

Φ_0 = the magnetic latitude of the auroral zone

II. 3—We select the point O'' as the origin of right-handed rectangular axes x, y, z and draw the $O''x$-axis through the point A, and the $O''y$-axis through the point B.

The point P is taken as the origin of right-handed rectangular axes x', y', z', and we draw the Px'-axis tangent to the Earth and towards the north pole, and the Pz'-axis in the direction of the Earth's center O'.

We obtain analytical expressions for the force due to the current-systems, using the expression

$$\mathbf{dF}=i\ \check{\mathbf{r}}_{\wedge}\mathbf{ds}/r^2 \tag{1}$$

$$=i\begin{vmatrix}\mathbf{i} & \mathbf{j} & \mathbf{k}\\ l & m & n\\ \dfrac{dx}{ds} & \dfrac{dy}{ds} & \dfrac{dz}{ds}\end{vmatrix}ds/r^2 \tag{2}$$

dF is the vector magnetic force at P due to a small vector-element of current **ds** centered at a point Q; i is the current-strength; **r** is the position-vector of Q with respect to P; $\check{\mathbf{r}}$ a unit-vector in the direction **r**; **i**, **j**, and **k** are unit-vectors in the directions x, y, z; l, m, and n are the direction-cosines of **r**; and dx/ds, dy/ds, and dz/ds are the direction-cosines of **ds**.

The majority of the integrals met with in the problem are readily expressed in terms of complete elliptic integrals, of which the first, second and third kinds are respectively

$$K(k)=\int_0^{\pi/2}\frac{dx}{\sqrt{1-k^2\sin^2 x}}$$

$$E(k)=\int_0^{\pi/2}\sqrt{1-k\sin\ x}\ dx$$

$$\Pi_1(k,\ n)=\int_0^{\pi/2}\frac{dx}{(1+n\sin^2 x)\sqrt{1-k^2\sin^2 x}}$$

where k is called the modulus and may take the values $0\leq k\leq 1$. In elliptic integrals of the third kind, n is called the parameter. When $-1\leq n\leq -k^2$, or $0\leq n\leq\infty$, $\Pi_1(k,\ n)$ is said to be circular; when $0\leq n\leq -k^2$, or $-1\leq n\leq\infty$, $\Pi_1(k,\ n)$ is said to be hyperbolic.

The integrals K and E are tabulated. The integral $\Pi_1(k,\ n)$ is not extensively tabulated but can be evaluated by methods given in treatises on elliptic functions.

It is also convenient here to define the functions

$$\left.\begin{aligned} G&=(k^4-8k^2+8)E/(k')^2-4(2-k^2)K\\ H&=(2-k^2)K-2E\\ I&=(2-k^2)E/(k')-{}^2 2K\\ J&=\alpha_1\Pi_1(k,\ n)+\beta_1\Pi_1(k,\ n')-2K\\ L&=2pK+(a-p)\Pi_1(k,\ n)\end{aligned}\right\} \tag{3}$$

where $k^2=4ap/[c^2+(a+p)^2]$; $(k')^2=1-k^2$; $\alpha_1=(\sqrt{c^2+p^2}+a)/(\sqrt{c^2+p^2}-p)$; $\beta_1=(\sqrt{c^2+p^2}-a)/(\sqrt{c^2+p^2}-p)$; $n=2p/(\sqrt{c^2+p^2}-p)$; $n'=-2p/(\sqrt{c^2+p^2}+p)$; and $n''=-(a+p)^2/[c^2+(a+p)^2]$. These refer to the point $P(a,\ b,\ c)$, referred to the coordinate axes x, y, z defined above.

II. 4—*The field of the current-system D_m*

II. 41—*The magnetic force due to L_1*—The lines of force due to a uniform circular current-line have been drawn previously and are given by Maxwell. We derive expressions for the components of force, directly applicable to points on a spherical Earth.

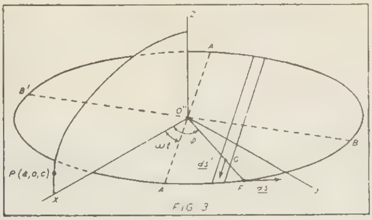

FIG 3

In Figure 3, the circle $ABA'B'$ represents the boundary around which flows the uniform current-line L_1 in an anti-clockwise sense about $O''z$ as axis. We require the magnetic force due to L_1 at a point $P(a, 0, c)$ in the xz half-plane.

We have from (2)

$$\mathbf{dL}_1 = i_1 \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ l & m & n \\ \frac{dx}{ds} & \frac{dy}{ds} & \frac{dz}{ds} \end{vmatrix} ds/r^2 \tag{4}$$

We also have $l=(x-a)/r=(p\cos\phi-a)/r$, $m=y/r=p\sin\phi/r$, and $n=-c/r$ after writing $x=p\cos\phi$, $y=p\sin\phi$. Also $dx/ds=\sin\phi$, $dy/ds=-\cos\phi$, and $dz/ds=0$, noting the direction of flow of current.

Hence the components of the force $\mathbf{dL}_1$ are as follows:

$$\left.\begin{aligned} \mathbf{dL}_{1x} &= -\mathbf{i}\ \ i_1cp\cos\phi d\phi/r^3 \\ \mathbf{dL}_{1y} &= -\mathbf{j}\ \ i_1cp\sin\phi d\phi/r^3 \\ \mathbf{dL}_{1z} &= -\mathbf{k}\ i_1(p-a\cos\phi)d\phi/r^3 \end{aligned}\right\} \tag{5}$$

Summing for all small current-elements of the current-line

$$\left.\begin{aligned} \mathbf{L}_{1x} &= -\mathbf{i}\ \ i_1cp\int_0^{2\pi}\cos\phi d\phi/r^3 \\ \mathbf{L}_{1z} &= -\mathbf{k}\ i_1p\int_0^{2\pi}(p-a\cos\phi)d\phi/r^3 \end{aligned}\right\} \tag{6}$$

where $r^2=c^2+a^2+p^2-2ap\cos\phi$; the component of force in the direction y vanishes because of symmetry.

We may express (6) in terms of the elliptic functions (3) as follows: $\mathbf{L}_{1x}=-\mathbf{i}\ i_1cfkI$ and $\mathbf{L}_{1z}=-\mathbf{k}\ i_1pfk^3[E/(k')^2-d\cdot I/k^2]$ where $d=a/p$, and $f=1/2a^{3/2}p^{1/2}$. Referred to axes x', y', z' (II.3)

$$\left.\begin{aligned} \mathbf{L}_{1x'} &= \ \ \mathbf{i}'i_1fk[(av+cu)I-pvk^2E/(k')^2] \\ \mathbf{L}_{1z'} &= -\mathbf{k}'i_1fk[(au-cv)I-puk^2E/(k')^2] \end{aligned}\right\} \tag{7}$$

where $u=\sin\Phi$, $v=\cos\Phi$, $a=R'v$ and $c=R'u-R\sin\Phi_0$.

II. 42—*The magnetic force due to* S_1—In the current-sheet S_1 the lines of current-flow are circles of latitude; they lie upon the spherical cap with apex O, and having the circle $ABA'B'$ as boundary. In estimating the current-strength of S_1 (B of Fig. 1), Chapman [3] had access to but scanty data; the distribution of current-lines in closest agreement with observation may therefore differ considerably from that here assumed. For this reason it appears practical to consider the simpler

problem obtained by supposing the polar cap of the Earth to be plane, so that S_1 becomes a uniform plane circular current-sheet.

We require the magnetic force due to this simplified form of S_1 at a point $P(a, 0, c)$ in the xz half-plane.

We first obtain the magnetic potential V due to S_1, for a point $P(0, 0, c)$ on the $O''z$-axis of symmetry (Fig. 2). For a current-line of S_1, of radius r, the magnetic potential at P is $i\Omega$, where i is the strength of current, and Ω is the solid angle at P subtended by the current-line. The potential V at P due to S_1 is thus given by

$$V=2\pi i'_1\int_0^p (1-c\sqrt{c^2+r^2})dr=2\pi i'_1(p-c\sinh^{-1}p/c) \qquad (8)$$

where p is the radius of S_1.

A potential symmetrical about an axis can be developed in the forms

$$A_0P_0+A_1\left(\frac{r}{p}\right)P_1+\ldots+A_s\left(\frac{r^s}{p^s}\right)P_s+\ldots \text{ for } r<p$$

$$A_0\left(\frac{p}{r}\right)P_0+A_1\left(\frac{p^2}{r^2}\right)P_1+\ldots+A_s\left(\frac{p^{s+1}}{r^{s+1}}\right)P_s+\ldots \text{ for } r>p$$

where A_s is a constant, P_s is a zonal harmonic of degree s, and (r, θ) are the polar coordinates of the point P. Thus expanding (8) in series involving powers of c/p and p/c, and comparing coefficients, we find that

$$\left.\begin{aligned} V&=2\pi i'_1\left[p-r\log\left(\frac{2p}{r}\right)P_1-\frac{1}{2.2}\left(\frac{r^3}{p^2}\right)P_3+\frac{1.3}{2.4.4}\left(\frac{r^5}{p^4}\right)P_5-\ldots\right] \text{ for } r<p\\ &=2\pi i'_1\left[\frac{1}{2.3}\left(\frac{p^3}{r^2}\right)P_1-\frac{1.3}{2.4.5}\left(\frac{p^5}{r^4}\right)P_3+\frac{1.3.5}{2.4.6.7}\left(\frac{p^7}{r^6}\right)P_5-\ldots\right] \text{ for } r>p \end{aligned}\right\} \quad (9)$$

If $S_{1r}=-\partial V/\partial r$, $S_{1\theta}=-\partial V/r\partial\theta$, are the components of the force at P, and in the directions of increasing r and θ, respectively

$$\left.\begin{aligned} S_{1r}&=2\pi i'_1\left[\left[\log\left(\frac{2p}{r}\right)-1\right]P_1+\frac{1.3}{2.2}\left(\frac{r^2}{p^2}\right)P_3-\frac{1.3.5}{2.4.4}\left(\frac{r^4}{p^4}\right)P_5+\ldots\right] \text{ for } r<p\\ S_{1r}&=2\pi i'_1\left(\frac{p^3}{r^3}\right)\left[\frac{1}{3}P_1-\frac{1.3.4}{2.4.5}\left(\frac{p^2}{r^2}\right)P_3+\frac{1.3.5.6}{2.4.6.7}\left(\frac{p^4}{r^4}\right)P_5-\ldots\right] \text{ for } r>p\\ S_{1\theta}&=2\pi i'_1\left[\log\left(\frac{2p}{r}\right)P'_1+\frac{1}{2.2}\left(\frac{r^2}{p^2}\right)P'_3-\frac{1.3}{2.4.4}\left(\frac{r^4}{p^4}\right)P'_5+\ldots\right] \text{ for } r<p\\ S_{1\theta}&=-2\pi i'_1\left(\frac{p^3}{r^3}\right)\left[\frac{1}{2.3}P'_1-\frac{1.3}{2.4.5}\left(\frac{p^2}{r^2}\right)P'_3+\frac{1.3.5}{2.4.6.7}\left(\frac{p^4}{r^4}\right)P'_5-\ldots\right] \text{ for } r>p \end{aligned}\right\} \quad (10)$$

$$S_{1x}=S_{1r}\sin\theta+S_{1\theta}\cos\theta,\quad S_{1z}=S_{1r}\cos\theta-S_{1\theta}\sin\theta \qquad (11)$$

It can also be shown that

$$\mathbf{S}_{1x}=-\mathbf{i}\, i'_1 c\int_0^{2\pi}\int_0^p \frac{\cos\phi\; r dr d\phi}{(c^2+\omega^2)^{3/2}}$$

$$\mathbf{S}_{1z}=-\mathbf{k}\, i'_1\int_0^{2\pi}\int_0^p \frac{(r-a\cos\phi)\; r dr d\phi}{(c^2+\omega^2)^{3/2}}$$

where $\omega^2=a^2+r^2-2ar\cos\phi$. These expressions can be converted into integrals which are convenient for numerical integration, as follows

$$\mathbf{S}_{1x} = -\pi^2\, \mathbf{i}\, i'_1 p \int_0^\infty \{\exp(-\lambda c)\{J_1(\lambda a)\}J_1(\lambda p)\mathrm{H}_0(\lambda p) - J_0(\lambda p)\mathrm{H}_1(\lambda p)\}\mathrm{d}\lambda$$

$$\mathbf{S}_{1z} = -\pi^2\, \mathbf{k}\, i'_1 p \int_0^\infty \{\exp(-\lambda c)\{J_0(\lambda a)\}J_1(\lambda p)\mathrm{H}_0(\lambda p) - J_0(\lambda p)\mathrm{H}_1(\lambda p)\}\mathrm{d}\lambda$$

Thus the components of the force are given in terms of Bessel and Struve functions. These alternative expressions for the force are convenient for ranges of r/p in which the series (10) converge slowly. The expression for S_1 may also be transformed in terms of elliptic integrals.

II. 43—*The magnetic force due to* S_2—The current-function for the spherical current-sheet S_2, referred to a point in the equatorial plane and upon its surface, is proportional to the perpendicular distance from this plane. Inside the spherical surface the magnetic force is uniform, of magnitude $4\pi\, i''_2/3R$; its direction is parallel to OO'.

Using this result and those of II. 2 and II. 3 we obtain the components of force due to the complete idealized current-system D_m.

II. 5—*The field of the current-system* S_D

II. 51—*The magnetic force due to* L_2 *and* S_3, *plane Earth*—In this special case we imagine that the current-system is plane, and flows above a plane Earth ($R=\infty$). The current-sheet S_3 is then uniform.

We choose an origin of right-handed rectangular axes x, y, z at the center O'' of the current-system (Fig. 3). We draw the $O''x$- and $O''y$-axes in the plane $ABA'B'$ so that the point $P(a, 0, c)$ lies in the xz-plane, and suppose that $a>0$, $c>0$.

The point P is fixed relative to the origin O'', but we suppose that the current-system rotates slowly in a clockwise sense about $O''z$ as axis, and with a constant angular velocity ω. We measure the time t from an instant t_0 when the line $O''A$ of the current-system is coincident with the $O''x$-axis. We consider the magnetic force at P at a particular time t such that $0<\omega t<\pi/2$ (Fig. 3). Actually, in the applications to terrestrial magnetism the current-system is fixed relative to the Sun, and the point P rotates with the Earth.

At the point B on the boundary $ABA'B'$, the current strength is i_2; at any other point F on $ABA'B'$ the current strength is $i_2 \sin(\phi-\omega t)$, where ϕ is the angle $FO''x$, measured in a clockwise sense about $O''z$ as axis.

Consider the current-sheet part S_3. Suppose that an elementary strip of the current-sheet flows in a direction parallel to $A'A$ and has a width $\mathrm{d}\mu$ measured in the direction $O''B$, and that the strip passes through any point G on S_3. The magnetic force at P, due to this elementary strip, is equivalent to that of a uniform linear current along the center of the strip, having the same total current strength $i'_2\mathrm{d}\mu$.

We denote by $\mathbf{ds}$ and $\mathbf{ds}'$ small vector elements of the circular current-line part L_2, and of the linear current in the strip, centered at F and G, respectively.

If $\mathbf{dS}_D$ is the vector-sum of the contributions to the force at P, due to $\mathbf{ds}$ and $\mathbf{ds}'$, using (2)

$$\mathrm{d}S_D = i_2 \sin(\phi-\omega t)\begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ l & m & n \\ \dfrac{\mathrm{d}x}{\mathrm{d}s} & \dfrac{\mathrm{d}y}{\mathrm{d}s} & 0 \end{vmatrix} \mathrm{d}s/r^2 + i'_2 \begin{vmatrix} \mathbf{i}' & \mathbf{j}' & \mathbf{k}' \\ l' & m' & n' \\ \dfrac{\mathrm{d}x}{\mathrm{d}s'} & \dfrac{\mathrm{d}y}{\mathrm{d}s'} & 0 \end{vmatrix} \mathrm{d}s'\,\mathrm{d}\mu/(r')^2 \qquad (12)$$

where **i**, **j**, **k** and **i**′, **j**′, **k**′ are unit-vectors in the directions x, y, z and x', y', z', respectively, l, m, n and l', m', n' are the direction-cosines of **r** and **r**′; and dx/ds, dy/ds, 0 and dx/ds', dy/ds', 0 are the direction-cosines of **ds** and **ds**′.

Hence the components of $\mathbf{dS}_D$ are as follows

$$\mathbf{dS}_{Dx}=\mathbf{i}\ c[i_2p \sin(\phi-\omega t)\cos\phi d\phi/r^3+i'_2 \sin \omega t\, ds'd\mu/(r')^3]$$
$$\mathbf{dS}_{Dy}=\mathbf{j}\ c[i_2p \sin(\phi-\omega t)\sin\phi d\phi/r^3-i'_2 \cos \omega t\, ds'd\mu/(r')^3]$$
$$\mathbf{dS}_{Dz}=\mathbf{k}\ [i_2p \sin(\phi-\omega t)(p-a\cos\phi)d\phi/r^3+i'_2\{(x-a)\sin\omega t-y\cos\omega t\}\, ds'd\mu/(r')^3]$$

The Jacobian $J=\dfrac{\partial(s',\mu)}{(x,y)}=1$, so that we may use $dxdy$ instead of $ds'd\mu$ as the element of area of the current-sheet S_3. Summing for all small vector elements **ds** and **ds**′ over the circuit, we find that

$$\left.\begin{aligned}
\mathbf{S}_{Dx}&=\mathbf{i}\ c\left|i_2p\int_0^{2\pi}\sin(\phi-\omega t)\cos\phi d\phi/r^3+i'_2\sin\omega t\int_{-p}^{p}\int_{-\lambda}^{\lambda}dxdy/(r')^3\right|\\
\mathbf{S}_{Dy}&=\mathbf{j}\ c\left|i_2p\int_0^{2\pi}\sin(\phi-\omega t)\sin\phi d\phi/r_3-i'_2\cos\omega t\int_{-p}^{p}\int_{-\lambda}^{\lambda}dxdy/(r')^3\right|\\
\mathbf{S}_{Dz}&=\mathbf{k}\Big[i_2p\int_0^{2\pi}\sin(\phi-\omega t)(p-a\cos\phi)d\phi/r^3+i'_2\sin\omega t\int_{-p}^{p}\int_{-\lambda}^{\lambda}(x-a)\\
&\quad dxdy/(r')^3-i'_2\cos\omega t\int_{-p}^{p}\int_{-\lambda}^{\lambda}ydxdy/(r')^3\Big],\ \text{for } 0<\omega t<\pi/2,\ a>0,\ c>0
\end{aligned}\right\}(13)$$

where $\lambda=\sqrt{p^2-y^2}$, $r^2=c^2+a^2+p^2-2ap\cos\phi$, $(r')^2=(x-a)^2+y^2+c^2$.

It can be verified that these expressions hold over the more extended range $\omega t\geq 0$, $a\geq 0$ and $|c|>0$.

For convenience we rewrite (13) in the form

$$\left.\begin{aligned}
\mathbf{S}_{Dx}&=\mathbf{i}\ c(i_2pI_1+i'_2\sin\omega t\cdot I_2)\\
\mathbf{S}_{Dy}&=\mathbf{j}\ c(i_2pI_3-i'_2\cos\omega t\cdot I_2)\\
\mathbf{S}_{Dz}&=\mathbf{k}\ (i_2pI_4+i'_2\sin\omega t\cdot I_5-i'_2\cos\omega t\cdot I_6)
\end{aligned}\right\}\quad(14)$$

The integrals $I_1\ldots I_5$ are expressible in terms of complete elliptic integrals of the first, second and third kinds. In terms of the functions (3) we find

$$\left.\begin{aligned}
&I_1=-\sin\omega t\, fG/kp,\ I_2=2afkJ=\pi/c-2afkL/(a+p),\\
&I_3=4\cos\omega t\, fH/kp,\ I_4=-\sin\omega t\, fk\,(I-d\cdot G/k^2),\\
&I_5=-4afpH/k,\qquad I_6=0
\end{aligned}\right\}\quad(15)$$

where $f=1/2a^{3/2}p^{1/2}$ and $d=a/p$. Using these results in (14) and noting that $i_2=i'_2p$, we deduce

$$\left.\begin{aligned}
\mathbf{S}_{Dx}&=-\ \mathbf{i}i'_2(p/a)^{1/2}c\sin\omega t\,[G/2ak-kJ/p]\\
\mathbf{S}_{Dy}&=\quad\mathbf{j}i'_2(p/a)^{1/2}c\cos\omega t\,[2H/ak-kJ/p]\\
\mathbf{S}_{Dz}&=-\ \mathbf{k}i'_2(p/a)^{1/2}\sin\omega t\,[pk\,(I-d\cdot G/k^2)/4a+H/k]
\end{aligned}\right\}\quad(16)$$

for the components of force due to the rotating current-system S_D, in the case of a plane Earth.

II. 52—*The magnetic force due to L_2 and S_3, spherical Earth*. The case of the current-system S_D appropriate to a spherical Earth presents greater difficulties in the analytical evaluation of the force; the current-

sheet part S_3 then flows over the curved polar spherical-cap surface with boundary $ABA'B'$.

Expressions for the components of force have been derived for points in the noon and evening half-planes of symmetry. It is hoped that an account of this somewhat lengthy work may be published elsewhere; later in this paper, a comparison of the results of computations of the force due to S_3, for a spherical Earth, with the results for a plane Earth show that the latter give an excellent approximation to the former in high latitudes.

If in (16) we remove the contributions due to the plane case of S_3, we obtain the components of force due to L_2, as follows:

$$\left.\begin{aligned} \mathbf{L}_{2x} &= -\ \mathbf{i}\ i'_2\, cfp \sin \omega t\, G/k \\ \mathbf{L}_{2y} &= \ \ 4\mathbf{j}\ i'_2\, cfp \cos \omega t\, H/k \\ \mathbf{L}_{2z} &= -\ \mathbf{k}\, i'_2\, fp^2k \sin \omega t\, (I - d \cdot G/k^2) \end{aligned}\right\} \qquad (17)$$

These give the components of force due to L_2 for any point in space, and hence for points on a spherical Earth.

II. 6—*Computations of force*

II. 61—In the computations, the Earth was supposed spherical and of radius 6370 km. The circular boundary $ABA'B'$, was taken to be directly above a magnetic latitude of 67°. In the case of a plane Earth the radius p of $ABA'B'$ was taken equal to the arc-radius of the circle of magnetic latitude of 67°.

Figures 4, 5, and 6 give the components of force in the directions x', y', z' (II. 2), due to the parts of the current-systems D_m and S_D considered separately for latitudes 50° to 90°. The variations with latitude are shown for points on the Earth in the noon and evening half-planes, $O'OA$ and $O'OB$, respectively, indicated by affixes A and B. The current strengths i_1, i_2, i''_1 and i''_2 corresponding to the parts L_1, L_2, S_1 and S_2, respectively, are each taken to be 100,000 amperes while i''_3 corresponding to S_3 is 200,000 amperes. For D_m the height assumed is 200 km; for S_D heights of 200 km and 100 km are used. In the case of D_m the computations are given for a spherical Earth, using the plane-Earth approximation in the case of S_1 for latitudes north of 55°; for points on the curved Earth south of this latitude it is assumed that S_1 intersects the Earth in the plane $ABA'B'$. In the case of S_D the computations were made for a spherical Earth in the 100 km-case; in the 200 km-case the computations for L_2 were made for a spherical Earth, but those for S_3 are for a plane Earth.

For regions where the computed components of the force are large, the errors in the force-values, due to the use of the plane-Earth approximation, are probably always within about five per cent.

Due to L_1 (Fig. 4), there is a marked minimum in the x'-component at the auroral zone; here also the z'-component reverses in sign, and it has a large maximum just inside and a smaller minimum just outside the zone. The components due to S_2 are comparatively small and vary slowly with latitude. In the case of S_1 (plane Earth) a broad minimum in the x'-component is attained inside the zone; outside the zone the x'-component decreases rapidly towards lower latitudes. The vertical component z' attains a marked maximum at the center of the zone, and a small minimum outside the auroral zone.

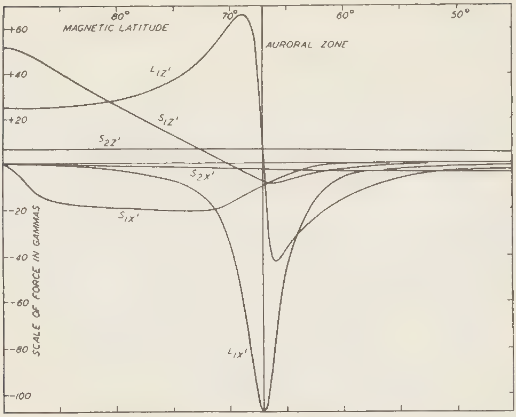

FIG. 4—COMPONENTS OF FORCE DUE TO PARTS L_1, S_1, AND S_2 OF THE IDEALIZED CURRENT-SYSTEM, D_m, HEIGHT 200 KM, FOR $i_1' = i_1'' = i_2'' = 100000$ AMPERES

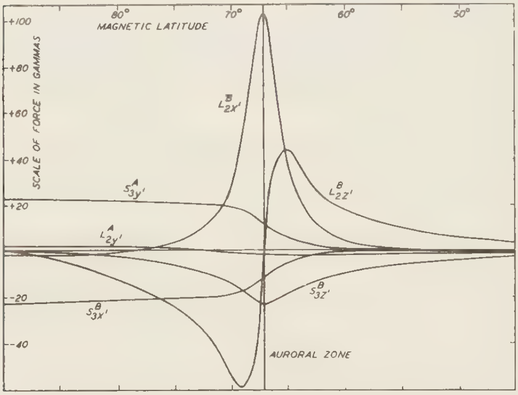

FIG. 5—COMPONENTS OF FORCE DUE TO THE PARTS L_2 AND S_3 OF THE IDEALIZED CURRENT-SYSTEM, S_D, HEIGHT 200 KM, FOR $I_2 = 100000$ AMPERES, $i_3'' = 200000$ AMPERES

The components of force for the parts of the current-system S_D (height 200 km) are illustrated in Figure 5. In the half-plane A the y'-component due to L_2 is small, and that due to S_3 (plane Earth) is comparatively large and nearly uniform in its variations with latitude inside the auroral zone; outside the zone, the force due to S_3 diminishes rapidly with decreasing latitude. In the half-plane B the variations due to L_2 resemble those for L_1 (Fig. 4), if reversed in sign, except in the region near the center of the auroral zone, where the vertical component due to L_2 is smaller than in the case of L_1. The z'-component due to S_3 (plane Earth) attains a minimum very near the auroral zone.

Figure 6 (note the change in the force-scale) shows the components of force due to S_D, for the height 100 km. The force near the auroral zone is about twice as great as in the 200-km case, but near the center of the auroral zone and in lower latitudes the decrease of the height by

one-half only slightly changes the force at the ground. The components due to S_3, computed for a spherical Earth are shown by dotted lines; it is clear that the force-values derived for a plane Earth are excellent approximations to those appropriate to a spherical Earth, for points near and inside the auroral zone.

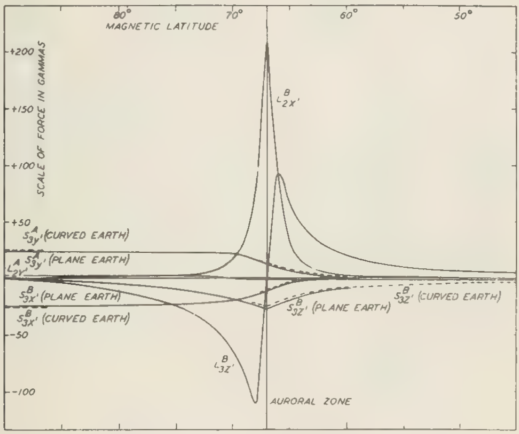

FIG. 6—COMPONENTS OF FORCE DUE TO PARTS L_2 AND S_3 OF THE IDEALIZED CURRENT-SYSTEM, S_D, HEIGHT 100 KM, FOR $i_2 = 100000$ AMPERES, $i_3'' = 200000$ AMPERES

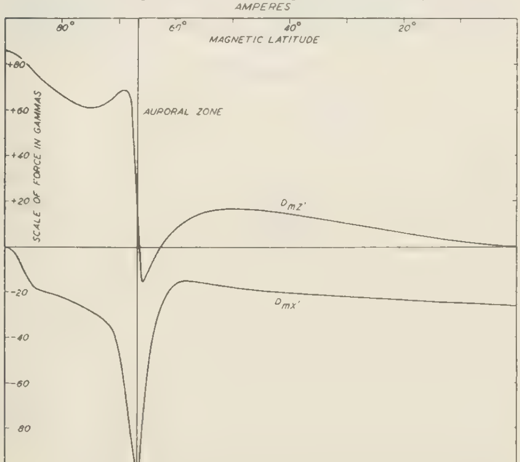

FIG. 7—FORCE DUE TO IDEALIZED CURRENT-SYSTEM, D_m, HEIGHT 200 KM, FOR $i_1 = 75000$ AMPERES, $i_2'' = 400000$ AMPERES, $i_1'' = 84000$ AMPERES

Figure 7 shows the components of force due to the world-wide current-system D_m, obtained by superposing the fields due to its parts, for the height of 200 km. The current-intensities used are the average values estimated by Chapman for the main phase of 40 moderate magnetic

storms. Figure 8 shows the components of force in the half-planes A and B due to the polar current-system S_D, for heights 100 km (I) and 200 km (II), using Chapman's estimate i_2 = 275,000 amperes for the average maximum strength of current at the auroral zone as found in the case of the 40 moderate magnetic storms.

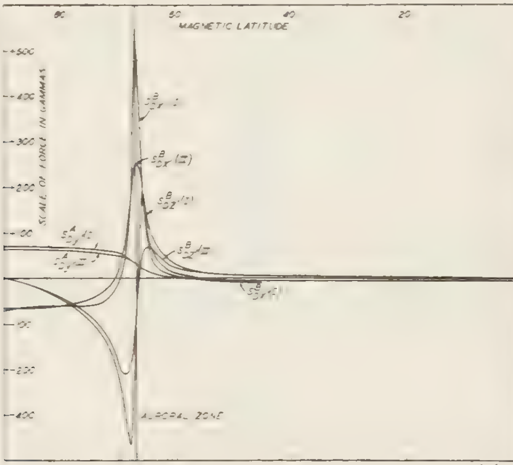

FIG. 8—FORCE DUE TO IDEALIZED POLAR CURRENT-SYSTEM FOR NOON (S_D^A) AND EVENING (S_D^B); i_1 = 275 000 AMPERES, CASE I = HEIGHT 100 KM, CASE II = HEIGHT 200 KM

We next examine the agreement of the computed values given in Figures 7 and 8 with observation.

III—*Comparison of the current-system C with observation*

III. 1—*Observational data*—The observational data consist of the daily means D_{mt} and the disturbance diurnal variations S_{Dt}, given by international disturbed days minus international quiet days, averaged in most cases over a period of about one year, mainly for stations in high northern latitudes; seasonal variations in D_{mt} and S_{Dt} are not considered separately.

Table 1 gives the stations used and various particulars affecting the data. Extensive new data are provided by stations of the Second International Polar Year, 1932-33. Stations of the First International Polar Year, 1882-83, are also included, for which values of D_m for all days minus quiet days were derived previously by Chapman [2]. The geographical distribution of the stations used and of annual mean vector-components of D_m are shown upon a map of north polar regions in Figure 9.

In Figure 10 are represented the force values D_{mt} and S_{Dt}, for stations of the years 1932-33, arranged mainly in order of decreasing magnetic latitude (the magnetic longitudes of the stations vary widely and certain minor adjustments have been made in the sequence order). On the left, a vector represents to scale the variations of S_{Dt} in the horizontal plane according to local time; the direction of the northward *geomagnetic*

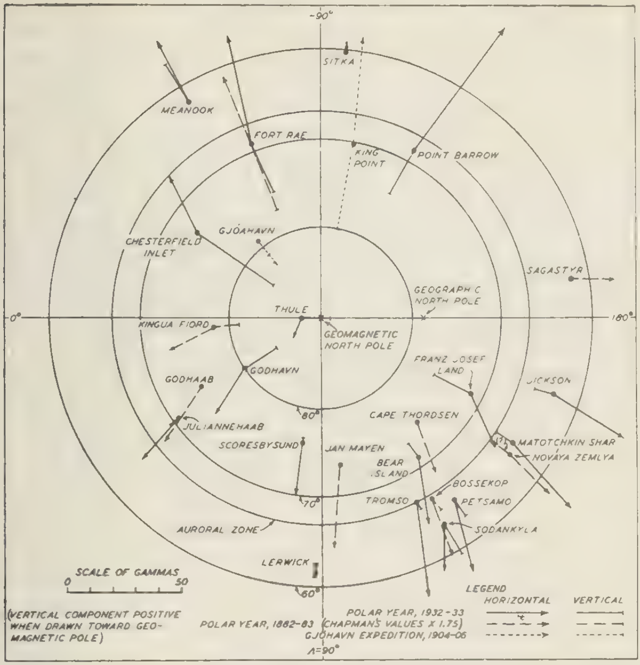

FIG. 9—VALUES OF DAILY MEANS, D_m, IN HIGH LATITUDES

TABLE 1—*Magnetic stations used*

Station	ϕ	λ	Φ	Λ	Ψ	D	Interval of time used	No. days
	°	°	°	°	°	°		
ıle	76.5N	68.9W	88.0N	0.7W	−0.6	−81.5	Aug. 1, 1932–July 31, 1933	60
lhavn	69.2N	53.5W	79.9N	32.9W	−17.6	−57.0	Aug. 1, 1932–July 31, 1933	60
resbysund	70.5N	22.0W	75.8N	81.4W	−36.2	−34.5	Feb. 1, 1933–July 1, 1933	23
esterfield Inlet	63.3N	90.7W	73.5N	35.5W	+14.9	−12.6	Sep. 15, 1932–Sep. 9, 1933	60
nz Josef Land	80.3N	52.8E	71.5N	153.3E	−32.2	+21.2	Year 1933	..
r Island	74.5N	19.2E	71.1N	124.1E	−37.9	−2.0	Oct. 1, 1932–Aug. 15, 1933	51
annehaab	60.7N	46.0W	70.8N	35.6E	−13.8	−43.5	Sep. 1, 1932–Aug. 1, 1933	60
t Rae	62.8N	161.1W	69.0N	69.1W	+24.1	+37.5	1932–1933	60?
nt Barrow	71.3N	156.7W	68.6N	118.7W	+33.0	+28.7	Oct. 1, 1932–July 31, 1933	50
msö	69.7N	18.9E	67.1N	116.2E	−30.8	−4.0	Aug. 1, 1932–July 31, 1933	57
samo	69.5N	31.2E	64.9N	125.8E	−27.6	+6.0	Aug. 1, 1932–July 31, 1933	..
totchin Shar	73.3N	56.4E	64.8N	146.5E	−22.4	+21.5	Year 1933	..
ankylä	67.4N	26.7E	63.8N	120.0E	−26.7	+3.0	Aug. 1, 1932–July 31, 1933	60
kson	73.5N	80.4E	63.0N	161.5E	−12.8	+28.5	Year 1933	..
wick	60.1N	1.2W	62.6N	88.6E	−23.6	−13.5	1926–1933	..
anook	54.6N	113.3W	61.8N	58.8W	+17.1	+26.5	Aug. 1, 1932–July 31, 1933	60
ka	57.0N	135.3W	60.0N	95.5W	+21.4	+29.5	1915–1923	..
kdalemuir	55.3N	3.2W	58.5N	82.9E	−20.4	+14.0	1911–1922	
Bilt	52.1N	5.2E	53.8N	89.4E	−18.9	−10.4	1911–1922	
din	52.3N	13.0E	52.4N	97.0E	−18.9	−6.6	1914–1924	

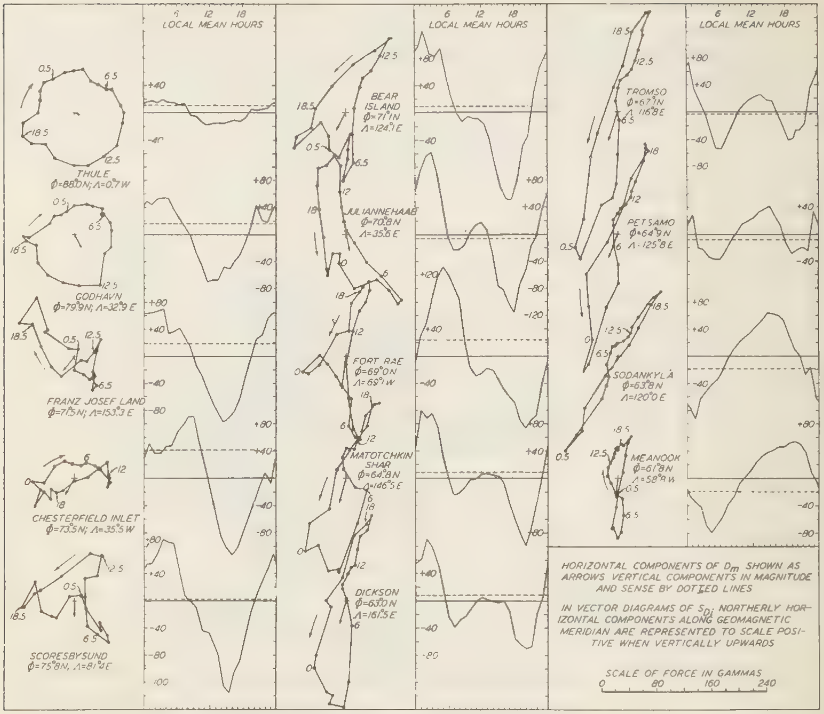

FIG. 10—VALUES OF D_{mi} AND S_{Di} IN NORTH POLAR REGIONS

meridian is vertically upwards along the diagram, in the case of each station. An arrow drawn to scale from the point representing the station shows the horizontal vector component of D_{mi}. On the right are shown the corresponding variations in the vertical component; the dotted line indicates the sign and magnitude of the vertical component of D_{mi}.

The force-variations show a very marked change with magnetic latitude. Near the center of the auroral zone the vector-diagrams for the horizontal plane are nearly circular. With decreasing latitude these vector-diagrams become more oval in shape, and show a tendency towards elongation in a direction roughly perpendicular to the geomagnetic meridian. Near the auroral zone the ovals are large and narrow, and elongated in a direction nearly transverse to the auroral zone, where the maximum amplitude in the poleward component of the force is attained.

The vertical components are reversed in sign, on either side, north or south of the auroral zone, which for the station Tromsö is near the magnetic latitude of 67°. Inside the zone the vertical component of S_{Di} shows a morning maximum and an evening minimum; the reversal of phase occurs near the auroral zone.

Asymmetries of the field in longitude are shown particularly by differences of several hours in local-time phase, for stations distributed near the same parallel of magnetic latitude. These are attributable to

the non-coincidence of the Earth's magnetic and geographic axes [2, 7]. In the present investigation our assumption of an ideal Earth will afford a good approximation to results for the real Earth, because the asymmetries in the field are sufficiently small in magnitude.

Figure 9 shows the geographical distribution of the force-components of D_{mt}. The data given by Chapman [2] for all days minus quiet days of the Polar Year, 1882-83 have been multiplied by a factor 1.75 to correct approximately for the difference in the magnetic intensity relative to that of the Polar Year, 1932-33. The data for both Polar Years show good general agreement. The D_m-field depends mainly on magnetic latitude but there is a certain dependence also on magnetic longitude. The mainly symmetrical character of the field, relative to the Earth's magnetic axis, is further confimed by a recent study of Slaucitajs and McNish [8], using extensive data for stations in lower latitudes.

The general characteristics shown are in good agreement with those found previously by Chapman [2], using data for all days minus quiet days of the Polar Year, 1882-83. There is also good agreement with data on the disturbance-diurnal variation studied by Lüdeling [9], Chree [10], Stagg [11], Kwei [12] and Ennis [13].

III. 2—*Comparison of the current-system D_m with observation*—In Figure 11 the variations of the force due to the current-system D_m are compared with observation, using current-intensities half as great as those for Figure 7. In the case of the northward component the general agreement is good as to the type of variation with latitude, but the discrepancies in magnitude are noteworthy. The computed magnitudes could of course be modified by assuming different heights or intensities of the current-system C. In lower latitudes about 30 to 40 per cent of the observed field is of origin internal to the Earth, and is additive for the northward component (Fig. 11, A), in the case of the storm-time variations. If this correction were introduced the agreement for lower latitudes would be improved. Near the auroral zone the approximation involved in assuming the zonal currents concentrated to a circular current-line will make the computed values of the force in this region somewhat too large.

For the vertical component (Fig. 11, B) the agreement for points outside the auroral zone appears good since the observed field should probably be reduced by a factor of about 0.4 due to induced earth-currents. Inside the auroral zone the observed vertical components show some irregular variations with latitude, possibly due in part to asymmetrical effects associated with longitude, and perhaps in part to inaccuracies in the vertical-force data. In general, the vertical components in this region are positive in sign and considerably smaller than the theoretical values, especially near the center of the auroral zone. Although induced earth-currents are likely to have made the observed vertical-force values too small, it appears that the current-function of the current-sheet S_1 should be altered. If most of the current in S_1 flowed near the auroral zone, and the current-strength of the current-line L_1 were also reduced, the fit between theory and observation would be much improved.

The eastward components of the horizontal force (Fig. 11, C), neglected in the comparison, are in general smaller than the northward

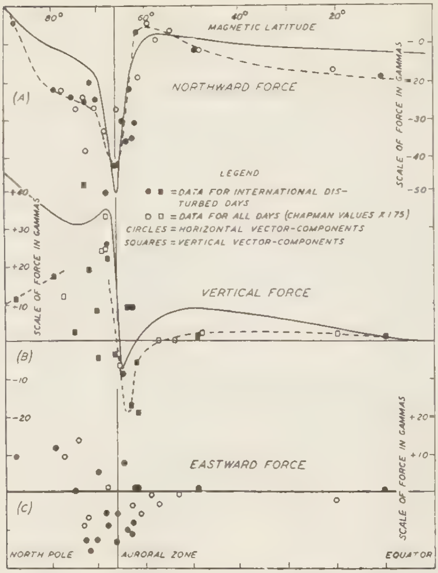

FIG. 11—COMPARISON OF IDEALIZED CURRENT-SYSTEM D_m, WITH OBSERVATION

components, especially at points near the auroral zone and in lower latitudes.

Slaucitajs and McNish [8] have recently made a spherical harmonic analysis of D_{mi}, using extensive data for stations south of the auroral zone and for one station inside the auroral zone. The current-distributions found are in good agreement with those of the current-system D_m here considered, and should afford improved estimates of the current intensities in lower latitudes. It would appear desirable to extend this analysis, using the more complete data for polar regions given here.

It has been suggested that an encircling current-ring in the plane of the magnetic equator may be the cause of the storm-time variation [3, 14] of magnetic storms. The slow rate of decay of this variation in low and middle latitudes following the attainment of the main phase of magnetic storms may also suggest that the currents mainly responsible for the variation in these regions flow high up or outside the Earth's atmosphere. This view becomes particularly interesting because of evidence found by Forbush [15] and by Hess and Demmelmair [16] of a decrease of a few per cent in cosmic-ray intensity during several intense magnetic storms, suggesting that cosmic rays from space are deflected away from lower latitudes by the action of an additional magnetic field external to the Earth.

Birkeland [17] suggested the existence of such a current-ring on the basis of his experiments, using cathode rays in the presence of a magnetized sphere representing the Earth, though there is doubt as to the legitamacy of these as illustrations of actual geomagnetic phenomena. Störmer [18] also suggested the presence of such a current-ring in con-

nection with his theory of the aurora. Chapman and Ferrara [19] have developed a tentative theory of magnetic storms, involving the presence of the current-ring at a few earth-radii distance from the Earth (much nearer than the ring proposed by Störmer), but they do not claim to have shown that such a ring will be formed.

It is of some interest to attempt an estimate of the radius of the current-ring, if real, using components of the force of origin external to the Earth and in low latitudes. Such data are afforded by the spherical harmonic analysis of D_{mi} made by Slaucitajs and McNish. Figure 12 permits a comparison between the latitude-distribution of the observed field (broken lines) and that of the field computed for a circular current-line in the plane of the magnetic equator and concentric with the Earth, for two different values of the ring-radius, namely four and two earth-radii; the contribution of atmospheric electric currents in polar regions to the computed field in lower latitudes is comparatively small (perhaps a maximum of 1γ in latitude 50° in the case of D_{mi}). The fit appears to be somewhat better for the current-ring of two than of four earth-radii, but the data hardly justify any definite decision between the two values of the ring-radius. These estimates agree well with results recently obtained by Forbush [15], using another method, and also considering the disturbance-fields of individual magnetic storms showing changes in cosmic-ray intensity. The current-intensity in the ring of

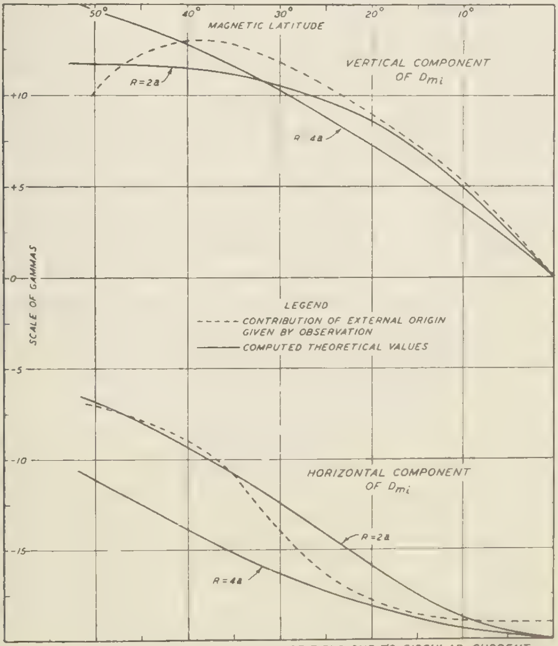

FIG. 12—COMPARISON WITH OBSERVATION OF FIELD DUE TO CIRCULAR CURRENT-LINE IN PLANE OF EQUATOR FOR CURRENT-INTENSITY=780 000 AMPERES WHEN R=4a, AND 330 000 AMPERES WHEN R=2a

radius $2a$ here considered would be about 330,000 amperes. This estimate gives the amount of current in the current-ring required to reproduce the values of D_{mi} (international disturbed minus quiet days) averaged for a year of sunspot-maximum. At the maximum of the main phase of very intense magnetic storms the amount of current may be 50 times as great.

The amount of energy [20] involved for a current-ring about two earth-radii in radius would of course be much less than in the case of the large size of some current-rings previously suggested, and need not necessarily nullify the Earth's field in the region where it is created, nor reverse the guiding forces supposedly responsible for its existence. It would not be concentrated in a current-line but may be somewhat diffusely distributed in space.

Chapman and Ferraro have suggested that the current in the ring would flow by virtue of a difference in the streaming velocities of ions and electrons within it. A moderate difference in their speeds would give the necessary amount of current, which could endure for several days in as far as collisions between them are concerned. The current would also decay due to the escape of charge at the surface of the ring, but the radial electrostatic forces within the ring causing this escape have not been subjected to exhaustive study; they consider this question of some importance in relation to the stability of the current-ring, and their calculation did not include also the effect on the ring of daily rotation of the Earth's magnetic axis, which describes a cone of 22°-angle about the geographic axis.* Their treatment deals with the ring after it is assumed to be created. In its present stage the theory of the current-ring is therefore incomplete, but seems worthy of further consideration in view of the new evidence of cosmic-ray effects [15, 16] during magnetic storms, which may be interpreted as unfavorable to the view that the storm-time variation in lower latitudes is mainly due to electric currents flowing within the Earth's atmosphere.

The existence of such a current-ring would mean that the contributions in polar regions from this source would be notably different from those in lower latitudes; the storm-time contribution due to the ring for polar regions would be greatest in the vertical component of the force. For the current-line, four earth-radii in radius considered in Figure 12, the vertical component is 18γ at the center of the northern auroral zone, and the horizontal component, which is -20γ at the equator, vanishes. The observed distribution of the daily means D_{mi} shown in Figure 9 could also perhaps be regarded as due partly to a difference in the size and intensity of the two opposed polar current-circulations of the current-system D (Fig. 1, A); in the case of magnetic bays, which contribute a considerable amount to the variation S_{Di} in high latitudes, the circulation of current near the dawn half-plane appears always to be very much larger and more intense than that near the evening half-plane. This asymmetry would give rise to a large contribution to D_{mi} in polar regions.

III. 3—*Comparison of the current-system S_D with observation*—In Figure 13 the computed values of the components of S_D are compared with observation. The assumed height of the current-system is 200 km,

*In a paper as yet unpublished, they find that the ring is not likely to be disrupted by a daily "wobble" due to the rotation of the Earth's magnetic axis (thus removing one suggested doubt [p. 353, of 3] as to the stability of the ring).

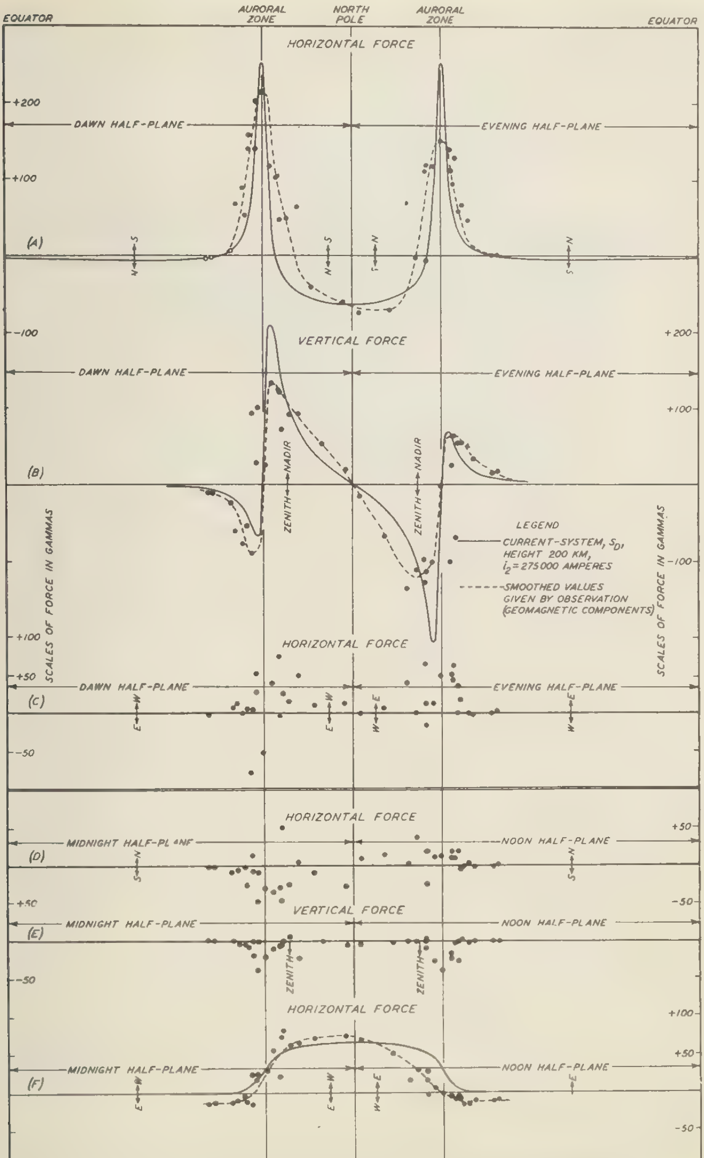

FIG. 13—COMPARISON OF THE IDEALIZED CURRENT-SYSTEM, S_D, WITH OBSERVATION

and the maximum strength of the current i_2 is 275,000 amperes. Smoothed broken curves have been drawn through the groups of points representing the geomagnetic components of force given by observation; these curves thus roughly average the values of the components of force along parallels of magnetic latitude, apart from minor differences in time-phase depending also on the longitude.

The general agreement between the computed and observed values is good in the case of all components. In the half-planes in which the theoretical components are zero, the observed values are usually comparatively small (C, D, and E of Fig. 13). Again, as in the case of the current-system D_m, induced earth-currents are in general likely to make the observed horizontal-force components too large, and the vertical components too small; if induced currents were allowed for, and the current i_2 were taken to be smaller and more broadly distributed laterally above the Earth, the general fit would be improved.

III. 4—*Further estimates of the height of the current-system* S_D—In these estimates of the height it is assumed that the current-system S_D flows in closed circuits in the atmosphere, and we consider the force-components as given by observation, for a point near the center of the auroral zone, and at a point very near the auroral zone.

Near the center of the auroral zone the horizontal force due to the current-sheet part S_3 is very nearly $2\pi i'_2$, the horizontal force due to a uniform infinite plane current-sheet. At Thule ($\Phi = 88°.0$), the daily average of the horizontal component is 66γ. Equating this to $2\pi i'_2$ we find $i'_2 = 1.05 \times 10^{-4}$ e.m.u./cm. Taking the diameter of the auroral zone to be 5.1×10^8 cm, the total current in S_3 becomes 535,000 amperes giving 267,000 amperes for the maximum strength i_2 of the current-line L_2 in either half of the auroral zone.

At the auroral zone, the maximum diminution in the poleward component of the force observed at Tromsö and Petsamo is about 215γ. This is due both to S_3 and L_2, and to the part S_4 of the S_D current-system flowing between the nothern and southern auroral zones. From Figure 5, the part due to S_3 is roughly 25/62 times the value, 66γ, of the horizontal component near the center of the auroral zone, or about 27γ. Neglecting the small contribution due to the part of the S_D current-system in lower latitudes, we find 242γ for the horizontal force due to L_2 at the auroral zone. If $i_2 = 267{,}000$ amperes and the force due to L_2 is approximately $2i_2/r$, where r is the perpendicular height of a uniform infinite linear current, we obtain $r = 53{,}000/242 \times 10^{-5}$ or 221 km. A rough correction for the currents flowing in lower latitudes (Fig. 2, F) reduces the value of 242γ at the auroral zone by 15γ, giving the height $r = 236$ km.

We have yet to consider the effect of induced earth-currents on the estimate of the height. Figure 14 illustrates the force-components due to L_2 (spherical Earth), and to an infinite linear current L'_2, tangential to L_2 at the point of maximum intensity of current and parallel to and above a plane Earth. The agreement is remarkably close in both components, in the region near the auroral zone.

The field due to L_2 varies as sin ωt, where t is the time, and has a period of 24 hours, neglecting the small easterly component L_{2y} of equations (17). Near the auroral zone it is therefore very nearly the same as that due to L'_2 if the current-intensity of L'_2 varied as sin ωt.

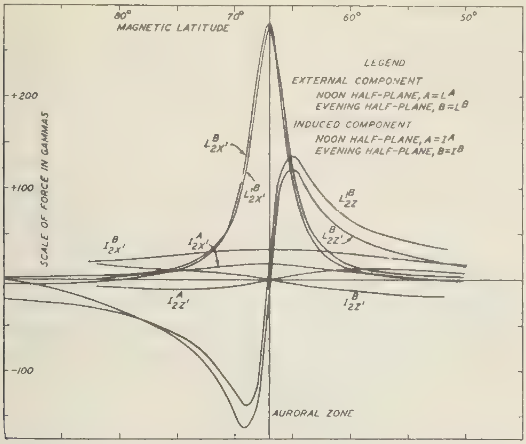

FIG. 14—COMPARISON OF FORCES DUE TO THE CIRCULAR CURRENT-LINE L_2 (SPHERICAL EARTH) AND THE INFINITE LINEAR CURRENT L'_2 (PLANE EARTH), HEIGHT 200 KM—ALSO COMPUTED INDUCED COMPONENTS DUE TO L'_2, FOR HALF-PLANES, A AND B, $i_2 = 275000$ AMPERES, $K = 3.65 \times 10^{-13}$ CGS

A. T. Price has computed the induced and inducing fields due to a linear current $i_2 \sin \omega t$, flowing parallel to and above a uniformly conducting semi-infinite medium with a plane surface, and has kindly loaned the results of these computations prior to publication; the analytical details of this work are very similar to those given by Buchholz [21].

We suppose the Earth plane, with an upper electrically non-conducting layer 200 km above a semi-infinite uniformly conducting core of conductivity $\kappa = 2.65 \times 10^{-13}$ CGS unit [Chapman 22]. We take the current L'_2 to be at a perpendicular height 200 km above the Earth, its current-strength as $-i_2 \sin \omega t$, with a period of 24 hours ($i_2 = 275{,}000$ amperes). The computed components of the induced field (I) at the Earth's surface are shown in Figure 14. The approximation so obtained is probably very rough, since the electrical conductivity appears to increase with depth; again, we have neglected the conductivity of the surface-layer of the Earth ($\kappa \sim 10^{-15}$), and the relatively thin layers of ocean having a conductivity of about 4×10^{-11} CGS.

We now return to our estimates of height, based on the data for Thule, Tromsö and Petsamo. Our previous estimate for the total current i''_2 in S_3 was 535,000 amperes. The station Thule is at a considerable distance from the intense zonal currents, as also are the stations in lower latitudes for which spherical harmonic analyses give the field of external origin as about 0.6 of the observed field. This correction applied to the data for Thule gives $i''_2 = 321{,}000$ amperes, so that $i_2 = 160{,}000$ amperes. The horizontal force at the auroral zone found previously for L_2 was 242γ. From Figure 14, taking $i_2 = 160{,}000$ amperes and the height as 200 km, the computed horizontal component of internal origin is 19γ. The contribution of external origin is thus estimated to be $242\gamma - 19\gamma = 223\gamma$. Using our previous method we obtain $r = 321{,}000/223 \times 10^{-3}$ or 145 km. The correction for the part of the S_D current-system flowing in lower latitudes becomes $15\gamma \times 10/6 = 25\gamma$, and gives $r =$

321,000/198$\times10^{-5}$ or 162 km, say 160 km. We regard this as our best estimate of the height of the idealized polar current-system S_D, and it appears that the application of the foregoing rough corrections for induced currents gives a height of the order 150 km at the auroral zone, assuming that the current-system flows in closed circuits in the atmosphere.

We have previously assumed that the zonal current was concentrated to a circular current-line. If we had taken into account the lateral distribution of the zonal currents of S_D (Fig. 1, *C*) the height computed would be less than that obtained above for the idealized version of the polar current-system. If the current-distribution within the space occupied by the zonal current were known, it would then be a mere matter of calculation to obtain a better estimate of the height. The average force-values used in the estimates are the averages for the year. Since we do know that the auroral zone expands and contracts laterally during magnetic disturbance we also know that the average zonal currents must have a lateral distribution, but little can be said with certainty of their vertical distribution in space. However, it is possible that some light on the matter of their lateral distribution is afforded by studying the zonal currents on individual days.

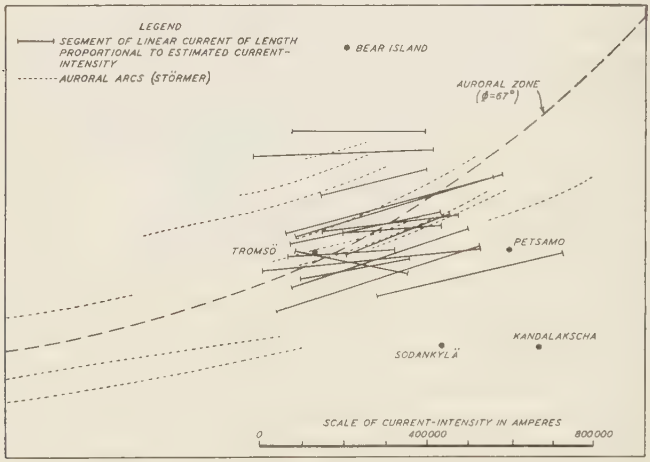

FIG. 15—LATERAL POSITIONS OF WESTERLY LINEAR ELECTRIC CURRENTS COMPUTED FOR TIMES OF MAXIMUMUM DISTURBANCE, $19^h 50^m$ TO $02^h 15^m$, GMT, FOR 15 MARKED MAGNETIC BAYS, POLAR YEAR, 1932-33, AND OF HOMOGENOUS AURORAL ARCS IN OTHER YEARS (AFTER STÖRMER)

Figure 15 shows the geographical positions of the linear currents computed for several of the relatively simple, large intensifications of the Earth's field known as bays, which appear frequently on the magnetograms for polar stations, and last from about one to five hours; these make a large contribution to the average S_D-variation. It was assumed that the disturbance-vectors at the time of maximum for each bay, measured relative to the mean hourly value immediately preceding the bay, for the stations Tromsö, Petsamo, Sodankylä and Kandalakscha, were due to an infinite uniform linear current. Using a modification of

a method originally due to Birkeland [17], the positions of the zonal currents were computed for each pair of stations in the group in turn, from the directions of the observed disturbance-vectors in the case of each bay separately, the effect of induced earth-currents being neglected. The lines drawn in the Figure represent approximately the mean positions and directions found for the current, and their magnitudes; using the magnitudes of the disturbance vectors at each station, it was found that an assumed height of 150-200 km for the linear current gave rather good agreement for the computed values of the current-intensities, for all stations of the group.

It would appear from the Figure that the latitude of the zonal currents varies from time to time, to north and south of the mean latitude of the zone of average maximum auroral frequency. Their directions of flow are probably influenced by the distribution of ionization near the auroral zone, and are in fact often roughly the same as those of quiescent homogeneous auroral arcs, near the height of 110 km, as found by Störmer (in other years) for this region of the Earth. The effects of such varying zonal currents will be among those averaged in obtaining the annual value of S_{Dt}. The average zonal current appropriate to S_{Dt} would therefore correspond more or less closely to a ribbon current-sheet, thereby making the foregoing estimates of the height of the current-system somewhat too high. From Figure 15, it appears that the lateral distribution extends over a distance of at least 400 km during the particular year considered (1932-33), with the greatest concentration of current near the zone of minimum auroral frequency, although at times of storm the zonal currents may move far to the south.

It is of interest to examine whether an improved fit with observation is obtained, in the cases of the dawn and evening half-planes assuming a lateral distribution of the part L_2 of the polar current-system S_D. We suppose the part S_3 has its southern edge in latitude 69°; using our previous estimate $i'_2 = 1.05 \times 10^{-4}$ electromagnetic unit as derived from the horizontal component at Thule, multiplying by 0.6 to obtain the current for the field of external origin, and by the diameter of S_3 and dividing by two, we find $i_2 = 146{,}000$ amperes, assuming that the current-circuits are closed. For the dawn half-plane the horizontal component observed is -215γ at the auroral zone: we add $-16/60$ of 66γ, the force at Thule, for the contribution due to S_3 at the auroral zone (Fig. 5), giving -233γ, to which we add 14γ to correct approximately for induced currents at the auroral zone (Fig. 14), giving -219γ. This is an estimate of the horizontal component of the force due to L_2, for a point at the auroral zone in the dawn half-plane. Using the same method the corresponding value is 151γ for the evening half-plane. We have neglected a small contribution due to the S_D current-system flowing in lower latitudes.

We now suppose L_2 distributed uniformly over a horizontal band having the same direction of flow, and centered above the auroral zone. The value of i_2 will vary but little with the height or width of L_2, if the current-system consists of closed atmospheric circuits, but the width of L_2 must increase as the height diminishes; the most probable height may be supposed to be that which gives the best fit with observation.

For a uniform infinite ribbon current-sheet of constant width centered directly above the auroral zone, the horizontal force at the auroral zone

is easily shown to be $2i_2\theta/b$, where $2b$ is the width of the ribbon-current, and θ is the angle subtended by b in the vertical plane for a point at the auroral zone. If the height r is 100 km, and $i_2 = 146{,}000$ amperes, the horizontal force due to L_2 found previously was -219γ for the dawn half-plane, after correcting for induced currents; using the additional relation $\tan\theta = b/h$ we find that $2b = 225$ km, or about 2° of latitude; this then is the estimate of the width of the zone-current. In the same way we find $2b$ for the evening half-plane to be 443 km or about 4° of latitude. These widths appear reasonable from the data on the lateral distributions of current indicated in Figure 15, although they may be somewhat too small; if the rather rough corrections here applied for induced currents at the auroral zone are too small, the computed widths would also be too small.

In A and B of Figure 16 the external field due to the modified "band"-form of the polar current-system S_D is compared with observation using the smoothed curves of Figure 13. The polar cap of the Earth has been assumed plane, and in the computations the ribbon-currents L_2 at the auroral zone and in the dawn and evening half-planes were taken to be infinite in length; the error due to this approximation is likely to be small (Fig. 14). The easterly components of the horizontal force shown in Figure 13 are neglected in this comparison. On the whole the fit obtained with observation for the height of 100 km is somewhat better

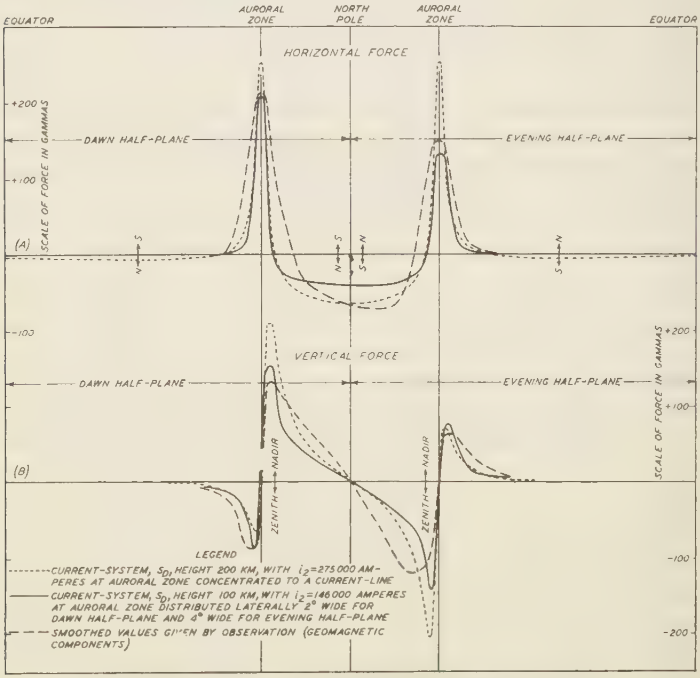

FIG. 16—COMPARISON OF THE IDEALIZED CURRENT-SYSTEMS, S_D, WITH OBSERVATION

than for the original idealized version of the current-system, at a height of 200 km. If the corrections applied for the effect of induced currents at the auroral zone were too small, as seems probable, the general fit obtained would be improved. These estimates of the height agree well with those for auroral-zone currents recently obtained by McNish [23] in the case of a magnetic bay, using a plane-Earth approximation such that the current-circuit was supposed completed at infinity, and effecting a separation of external and internal parts of the field on the basis of general potential-theory.

IV—*The field of the electric current-system B*

IV. 1—The current-system C is not the only possible one compatible with the observed surface-field of disturbance, and we next compare the fields of current-systems B and C, current-system C having been previously compared with observation.

According to Birkeland [17] charged corpuscular rays from the Sun are drawn in towards the Earth in the sharply wedge-shaped space in the polar regions, always whirling around the lines of magnetic force. In the first instance they may approach the Earth in spirals of diminishing radius of curvature, later to spiral out into space (Fig. 17, A), or as generally happens, pass the Earth with an average curvature, such as shown by the curve C of Figure 17, or less frequently, with a loop, such as the curve E of Figure 17 shows [page 99 of 17]. These give rise to bundles of rays such as are represented in B and D of Figure 17, producing magnetic fields at the Earth's surface approximately equivalent to simple currents.

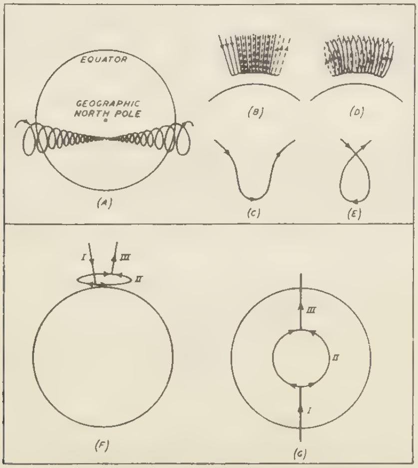

FIG. 17—ELECTRIC CURRENT-SYSTEM OF BIRKELAND

In F and G of Figure 17 are shown views of an idealization of Birkeland's model, corresponding to sets of loops as B and D in Figure 17 for the case of the S_D variation. The linear current I enters at the auroral zone tangentially to a line of magnetic force due to a doublet representing

the main field of the Earth. This current divides into equal semicircular parts forming the circular current-line II, flowing at constant height above the Earth's surface, and flows out into space in the form of the linear current III, again tangential to a line of force of the Earth's field.

IV. 2—*The magnetic force due to the current-system B*—We evaluate the force due to B for points on the Earth in the noon and evening half-planes. We first consider the force in the noon half-plane. The methods employed are similar to those used for the current-system C. Using the axes x, y, z and x', y', z' defined in II. 2, all the components of force in the noon half-plane vanish, except that in the direction y'. The eastward component at a point $P(a, 0, c)$, taking the radius of the circular part II to be unity becomes

$$\mathbf{F}_y' = \mathbf{j}'\, ik\, [2a(\tan \beta/2 + k' \tan \beta'/2)/k' + c\,(1-k')\, k']/a^{3/2} \qquad (18)$$

where $k^2 = 1-(k')^2 = 4a/[c^2+(1+a^2)]$. If m and m' are the perpendiculars from the point P to the current-lines I and III produced, meeting I and III in the points M and M', respectively

$$\beta = \tan^{-1} m/AM, \quad \beta' = \tan^{-1} m'/CM'$$

The parts I and III produced meet the magnetic axis of the Earth in the point O''', with coordinates relative to the axes x, y, z given by $(0, 0, c')$, each inclined at an angle α to the magnetic axis. The angle β is measured from the line AO''' in a clockwise sense about the axis Ay; the angle β' is measured from CO''' in a clockwise sense about the axis $-Ay$.

For the point $P(0, b, c)$ in the evening half-plane we find the force components due to current-system B given by

$$\left.\begin{aligned} \mathbf{F}_y &= 2\mathbf{i}\, i\,[2\,(\cos\alpha + c\sin\alpha)/r_0(r_0 - c\cos\alpha+\sin\alpha) - ckU/b^{3/2}(k')^2] \\ \mathbf{F}_z &= -2\mathbf{k}\, i\,[b\sin\alpha/r_0\,(r_0 - c\cos\alpha+\sin\alpha) \\ &\quad - k\,\{k^4/\triangle_1 + k^2\,(E-2E_1) + bU/b^{3/2}\,(k')^2\}] \end{aligned}\right\} \qquad (19)$$

where

$$k_2 = 4b/[c^2+(1+b)^2], \quad (k')^2 = 1-k^2, \quad \triangle_1 = \sqrt{(2-k^2)/2}, \quad r_0 = \sqrt{(1+b^2+c^2)}$$
$$U = 2\,(k')^2(K-2F_1) - (2-k^2)\,(E-2E_1) - k^2\,(2-k^2)/\triangle_1$$
$$K = F\,(k, \pi/2), \quad E = E\,(k, \pi/2), \quad F_1 = F\,(k, \pi/4), \quad E_1 = E\,(k, \pi/4)$$

and F and E are elliptic integrals of the first and second kinds, respectively.

IV. 3—*Comparison of the fields of current-systems B and C* Figure 18 illustrates the computed fields due to the current-systems B and C, for points on a spherical Earth of radius 6370 km, for an auroral zone at a magnetic latitude of 67°. The curves due to the current-system B, numbered 1, 2, 3 and 4, refer to assumed heights, for the part II of B, of, respectively, 100 km, 300 km, 500 km and 700 km above the Earth. The current strength i has been adjusted so that the northward components of force in the evening half-plane are the same, for the four heights, as for the current-system C; the latter current-system was assumed to be at a height 200 km above the Earth and to have a maximum current-intensity of 275,000 amperes at the auroral zone (dotted curves).

In the dawn and evening half-planes the variations with latitude

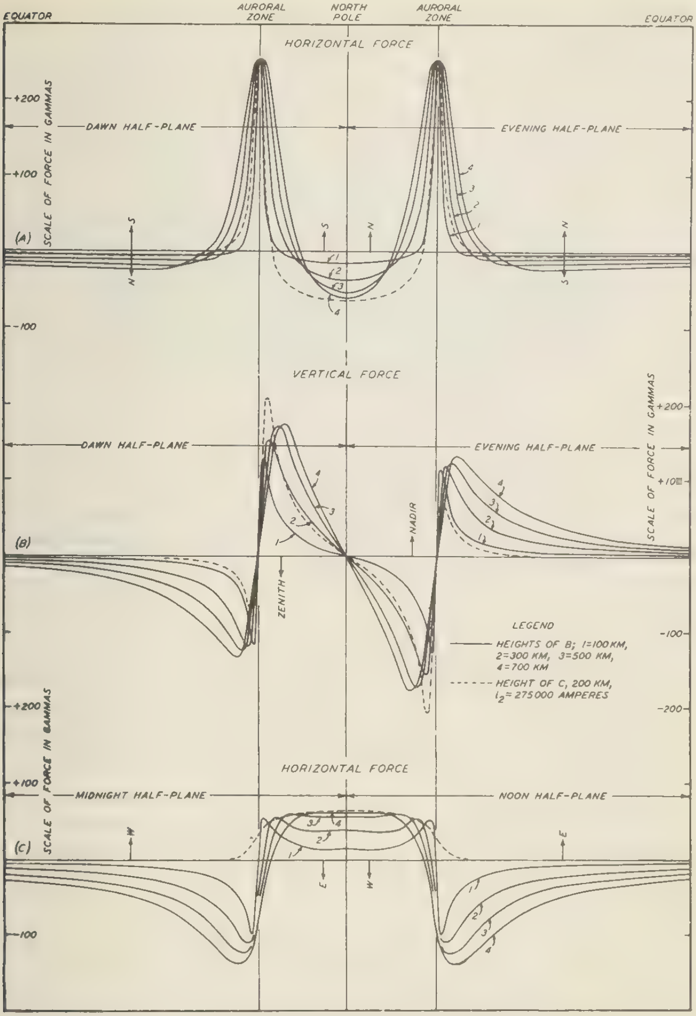

FIG. 18—COMPARISON OF FIELDS OF IDEALIZED CURRENT-SYSTEMS, AFTER BIRKELAND, B, AND AFTER CHAPMAN, C

of the northward component, for current-systems B and C, are roughly similar in general type, for points near the auroral zone. The closest agreement near the center of the auroral zone is attained when the height of current-system B is 700 km above the Earth. Just inside the auroral zone the differences are marked for all heights of B, and therefore B is in unsatisfactory agreement with observation (Fig. 13). Birkeland

did not have the opportunity of comparing the field due to B with observation, for points near the center of the auroral zone.

In the vertical component, for points inside the auroral zone, the agreement is fairly good; outside the zone the vertical components for greater heights of B give much larger values than in the case of C.

In the noon and midnight half-planes the force-components inside the auroral zone are in best agreement for the heights 500 km and 700 km of B; outside the auroral zone the agreement is bad for all the four different heights of B, and also in poor agreement with observation.

In the case of Birkeland's model a good fit with observation near the auroral zone implies a poor fit with observation near the center of the auroral zone, and *vice versa*, and this fact, together with other objections which might be raised [3] suggests that the current-system B be discarded as unsatisfactory in its agreement with observation. It does not appear possible that a drastic modification of the model will result in a great improvement with the general fit obtained with the observed data as given here.

V—*Conclusion and discussion*

On the whole the partial current-systems S_D and D_m proposed by Chapman show encouraging success in reproducing the force-components of average geomagnetic disturbance given by observation. There is therefore a definite probability that these current-systems, or at least their polar parts, approximately correspond to real atmospheric current-systems. The polar current-system S_D would appear to form a closed or balanced system of current, and would thus require no current supply from sources external to the Earth; if this balance of current is very nearly complete, the current-system would flow very near or within the E-region of the atmosphere, at a height roughly about 100 km above the Earth. The results of radio observations also suggest that this region is more favorable to the conduction of electric currents than are those at higher levels, where the collisional frequencies of ions and electrons are lower and where the number of free ions is in all probability very much less than in or near the E-region. It seems possible that the S_D current-system may be caused by dynamo-action produced by the motion of conducting air-masses across the Earth's permanent magnetic field, incoming particles of solar origin contributing at some times more than at others to the conductivity of the conducting air-masses or layers.

The form of the current-system D_m appears less suitable for the purposes of estimation of height. The observed world-wide distribution of the disturbance D_m could be reproduced by atmospheric current-systems of the type proposed by Chapman, which if assigned to different heights would differ from one another only slightly in general form and intensity, except in the region near the auroral zone. The comparisons here made for the height of 200 km suggest that the current-system D_m, as given by Chapman, should be modified in the region inside the auroral zone, by making the current-intensity increase more rapidly with distance southwards measured from the center of the auroral zone. If the height of the current-system were lowered from 200 km the amount of current flowing near the auroral zone would be reduced, and consequently the

vertical component near the center of the auroral zone would be reduced, improving the agreement with observation. Since the separation of the system C, especially in the polar regions, into the parts D_m and S_D, is merely made for convenience, and since the currents themselves, in that region are likely to form a connected whole, the heights of the currents in the D_m and S_D parts will be the same. On the other hand, the slow decay of the storm-time field following the attainment of the main phase of a magnetic storm suggests that the currents responsible for the long enduring after-field of the storm, in D_m, flow in a region where the rate of collisional frequency of ions, atoms, and electrons is low, or that the currents mainly responsible for the storm-time variation in lower latitudes flow either at high levels in the atmosphere, or in an external current-ring. Little is known of the nature of the storm-time variation in polar regions, except the present indications given by the values D_m. A dynamo-theory for the current-system D_m would suggest a downward motion of conducting air during the initial phase of storms, followed by an upward expansion or flow during the main phase, with a gradual subsidence perhaps involving less conducting air, as in Chapman's first theory, though the causes he assigned for the vertical air motions cannot be upheld. A dynamo-theory for the current-system S_D may involve an atmospheric circulation of the air such that the electric currents are mainly initiated in the auroral zone; this air-motion could be vertical, although it is more likely to be horizontal on general dynamical grounds [2, 7]. Our present knowledge of the air-movements in the upper atmosphere is too meager adequately to test these possibilities.

A current-ring, a few earth-radii in radius, concentric with the Earth and in the plane of the magnetic equator, could also reproduce the observed latitude-distribution of D_{mt} in low latitudes, should it be possible for such a current to exist.

The electric current-system of Birkeland gives rise to a disturbance-field shown to be inconsistent with observation in several important respects.

The observed average characteristics of S_{Dt} and D_{mt}, given by the new and extensive data here examined, are in good general agreement with expectations based on previous data. Features asymmetrical with respect to the Earth's magnetic axis are in evidence, and the intense and highly differentiated average magnetic field near the auroral zone varies in position through some degrees of magnetic latitude, for points in different longitudes around the Earth.

The writers are indebted to Dr. D. la Cour, Director, Danish Meteorological Institute and to J. Patterson, Director, Meteorological Service of Canada, for the loan of valuable magnetic data. Thanks are also due to Dr. J. A. Fleming for facilitating the completion of various extensions to the work, and to W. C. Hendrix, Department of Terrestrial Magnetism, Carnegie Institution of Washington, for drawing the diagrams of this paper. Grateful acknowledgement is also made of financial assistance given to one of us (E. H. V.) by the International Association of Terrestrial Magnetism and Electricity and the National Research Council of Canada.

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DATA FOR ABSOLUTE STORMINESS FOR THE POLAR STATION GJÖAHAVN FOR THE YEAR 1904

By K. F. Wasserfall

Roald Amundsen took a set of Eschenhagen variation-instruments for use on the Gjöa Expedition during 1903 to 1906 and at his base-station Gjöahavn (latitude 68° 37′.6 north and longitude 95° 54′.8 west). That station was occupied from November 1903 to May 1905; hence almost complete hourly data for *D*, *H*, and *V* could be published for that period.

When the results from the expedition were published,[1] there was no opportunity to undertake special studies of the variation of the magnetic

[1]Geofys. Pub., 7 (1933).

Table 1—*Daily data for absolute storminess for D at Gjöahavn, 1904*

Day	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	1129	350	324	1877	822	573	1068	969	650	460	638	694
2	595	513	387	1002	792	247	338	1207	782	323	943	249
3	907	190	627	1237	662	387	727	3046	834	199	637	709
4	1109	819	969	556	469	354	519	1539	264	285	1666	610
5	845	688	343	415	245	883	391	464	756	337	919	605
6	312	509	329	362	282	1210	2118	487	586	580	367	242
7	207	611	267	1050	254	451	1259	353	635	1566	298	252
8	210	429	280	676	980	222	500	419	656	843	283	108
9	809	806	333	650	370	244	1071	685	624	514	258	338
10	952	562	190	619	247	667	381	673	298	290	125	142
11	309	377	538	1237	540	318	400	226	1082	291	176	119
12	408	376	475	524	1808	546	317	295	540	415	89	161
13	228	490	249	569	2354	227	872	516	369	1560	113	127
14	93	635	130	255	1145	495	1572	657	367	707	147	525
15	911	1017	172	318	465	2864	580	732	234	439	549	401
16	1045	1004	117	189	582	1603	536	1105	622	323	906	242
17	242	450	129	472	852	608	742	1095	302	255	906	134
18	174	586	269	1408	504	443	583	739	547	260	794	141
19	113	279	209	1276	718	287	208	434	302	123	181	103
20	354	94	326	203	474	746	556	396	338	217	133	199
21	502	167	138	214	496	660	427	1066	253	1390	229	426
22	351	306	234	647	642	295	449	929	414	520	251	151
23	185	520	164	246	726	380	647	323	241	241	97	190
24	327	280	298	485	773	364	194	312	822	306	291	121
25	181	296	313	741	190	446	428	264	1209	415	909	81
26	127	219	899	415	385	1117	903	166	560	249	737	550
27	166	262	579	257	1528	1114	863	345	347	742	680	279
28	897	314	284	280	2409	496	788	273	243	752	180	196
29	665	326	481	811	1286	423	600	717	290	444	355	372
30	827		325	798	792	372	1113	810	494	1094	713	168
31	529		612		910		325	535		829		108
Mean	506	465	354	659	797	635	692	703	522	547	485	282

elements, because the data collected were so abundant that publication had to be limited to the hourly values for the three elements D, H, and V. It has seemed, however, worth while to make further use of these valuable data and the present paper represents one of the special variation-studies based thereon.

In our publications for the two Norwegian stations Tromsö and Dombås, we introduced the quantity "Absolute storminess" (AS) to express magnetic activity. AS denotes the diurnal sum of positive and negative hourly values in the tables for "Storminess." Regarding the storminess-tables we refer to our series of publications[2]—especially Nos. 2, 9, and 10 where the three variation-components Q, S, and C are defined. As will be seen, the ordinary hour-ordinate O has here been divided into the above-mentioned variation-components, so that

$$O = Q + S + C$$

[2]Publikasjoner fra Det Norske Institutt for Kosmisk Fysikk.

Table 2—*Daily data for absolute storminess for H at Gjöahavn, 1904*

Day	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	807	571	185	1642	1682	552	1767	786	911	740	490	517
2	542	432	349	1357	909	327	746	1515	969	364	721	318
3	560	282	554	967	1189	350	489	2357	1161	296	483	705
4	582	714	709	628	1286	390	683	1261	365	268	946	459
5	603	755	441	439	271	1511	722	879	679	442	453	422
6	445	656	450	588	440	2146	2650	873	937	587	406	310
7	140	547	275	642	556	1086	1324	312	563	867	439	202
8	150	520	305	329	1982	303	617	466	1337	655	308	218
9	599	588	353	471	684	473	1603	354	910	402	266	370
10	730	566	178	1011	353	786	443	850	1176	241	198	206
11	1005	387	693	1823	493	383	337	528	650	160	264	183
12	705	443	577	1109	2746	541	387	249	595	198	224	98
13	249	505	506	629	2180	223	1608	387	350	1479	98	193
14	111	576	162	379	1662	709	2878	847	378	709	127	551
15	771	805	135	473	295	2942	1482	1483	338	390	367	474
16	870	1183	206	177	820	2336	764	1760	1286	441	795	303
17	317	405	175	622	1152	1179	1055	818	293	181	781	241
18	179	673	456	1941	576	616	466	817	296	85	466	317
19	91	255	236	1936	1844	336	1117	264	116	233	214	110
20	301	141	460	347	551	1242	1272	567	105	261	151	241
21	560	139	189	243	1070	797	534	1103	483	932	124	411
22	460	397	133	724	1129	274	282	965	321	359	372	151
23	149	675	344	770	1333	668	836	457	453	401	149	126
24	340	457	407	989	1551	313	607	392	593	352	221	95
25	205	622	571	895	474	779	607	245	776	652	656	144
26	84	312	990	855	863	1222	1554	297	485	358	777	360
27	161	263	891	243	1462	1159	743	261	198	307	393	260
28	856	278	635	568	2515	928	1223	275	333	511	298	264
29	691	548	672	1228	1213	648	547	1561	451	449	414	251
30	654		374	1164	883	917	1483	1144	154	431	536	141
31	308		385		716		609	1255		773		136
Mean	459	506	419	840	1125	871	1014	817	588	469	405	283

The AS-data for magnetic activity have of course been worked out for the three elements D, H, and V, but, in our year books, graphical illustrations of the day-to-day variation in AS have only been given for the horizontal force-component, because this element is the most perturbed. In No. 10 of the above-mentioned series, I have published some comparative studies of such data for AS and the figures given by van Dijk as international character-numbers. From these studies it appears that AS for the D-component represents the quantity which shows the closest relation to van Dijk's figures.

Tables 1, 2, and 3 give AS for D, H, and V at the polar station Gjöahavn for 1904, and Figure 1 contains the graphs. It might also, in this case, be of interest to compare these figures for AS with international character-numbers, but, as far as I know, van Dijk's character-numbers -consisting only of 0, 1, and 2 to indicate degree of perturbing

Table 3—*Daily data for absolute storminess for V at Gjöahavn, 1904*

Day	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.*	Sep.*	Oct.	Nov.	Dec.
1	1330	1096	182	1772	1776	876	714	......	......	372	722	572
2	781	1442	286	1700	1313	326	437	......	......	413	833	180
3	767	250	243	1008	1286	590	188	......	......	183	594	848
4	1032	456	395	925	856	549	523	......	......	319	1214	492
5	827	715	591	506	808	656	232	......	......	563	532	634
6	607	497	176	574	704	1668	650	......	......	462	435	255
7	232	467	84	419	846	668	724	......	......	1366	591	242
8	137	951	133	311	590	378	325	......	......	816	310	138
9	388	804	161	684	266	318	235	......	......	507	220	252
10	400	607	165	410	779	663	261	......	......	281	164	190
11	868	485	445	561	558	533	204	......	......	304	175	199
12	576	291	556	972	1192	653	266	......	......	512	94	163
13	503	291	204	444	2409	409	471	......	......	795	73	131
14	230	591	131	345	1246	980	1215	......	......	402	152	360
15	416	1084	58	322	447	1663	526	......	......	206	399	492
16	1356	1674	155	346	741	1790	296	......	......	335	1116	805
17	261	467	60	543	910	741	581	......	......	448	1784	172
18	268	940	259	1405	488	888	263	......	......	269	1702	203
19	249	512	110	1222	842	230	563	......	......	346	433	174
20	361	606	130	221	574	582	610	......	......	353	136	266
21	614	572	367	309	981	628	417	......	......	1039	285	738
22	851	369	588	843	1062	421	371	......	......	310	244	118
23	245	306	572	591	1031	547	453	......	......	386	115	88
24	364	182	682	674	981	306	268	......	......	283	231	116
25	358	150	420	1129	627	841	404	......	......	397	770	88
26	119	138	535	1429	511	992	789	......	......	409	433	459
27	308	190	316	383	1487	1201	1318	......	......	614	629	240
28	375	298	288	404	1621	685	392	......	......	823	254	289
29	1334	179	283	932	1439	519	570	......	......	211	444	347
30	719		397	1079	1129	249	512	......	......	752	270	247
31	1100		377		761		240	......		986		246
Mean	580	576	302	748	976	682	481	......	......	489	512	314

*Data for August and September 1904 are omitted as the instrument was out of order during part of the time.

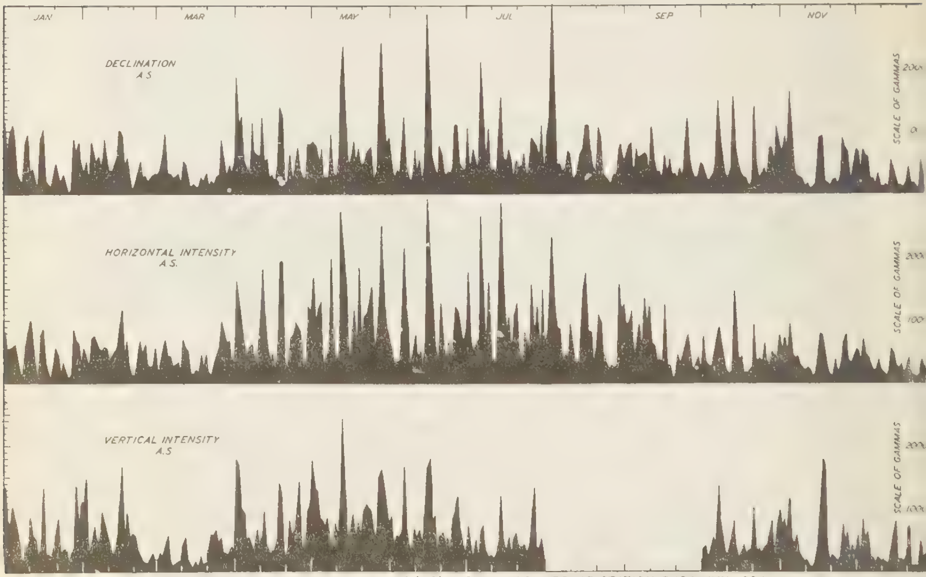


FIG 1—GRAPHS ABSOLUTE STORMINESS (A S) FOR D, H, AND V, POLAR STATION GJOAHAVN, 1904

force—were not introduced until after 1904. However, in the year book of the Potsdam Magnetic Observatory for 1904[3] the tables contain a column headed "Charakter," where—separately for forenoon and afternoon—figures are given for the three elements *D*, *H*, and *V*, according to a scale of 1 to 5, 1 indicating very quiet curves and 5 the most disturbed curves.

From the table of character-numbers for Potsdam—used for the present graph—I have taken the mean figures given by the year book for forenoon and afternoon. The figures are only whole numbers, but using the mean for morning and afternoon we get whole numbers with decimals 0.0 and 0.5. For instance, if the figure is 1 for the forenoon and 2 for the afternoon, we get as the mean 1.5.

The graph shows in the first place the universality of such numbers—either they are represented by *AS* or introduced in the figures according to the limited scale of 1 to 5. On the other hand, however, the comparison shows plainly that one gets a much more representative expression for the variation in activity when figures for *AS* are used, besides the character-numbers depend on judgment, while the figures for *AS* are obtained directly by summing up the positive and negative figures in the storminess-tables, and are accordingly much more homogeneous.

[3]Ergebnisse der magnetischen Beobachtungen in Potsdam in den Jahren 1903 und 1904, Berlin, Veröff. met. Inst., Nr. 203 (1908).

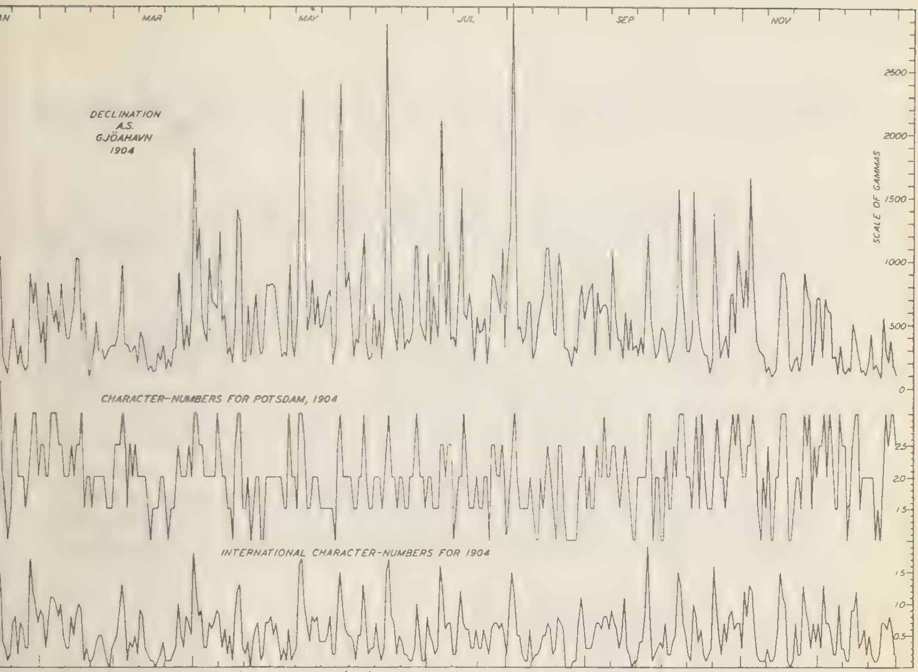


FIG 2—COMPARISON ABSOLUTE STORMINESS (AS) FOR GJOAHAVN, BASED ON DECLINATION AND CHARACTER-NUMBERS

An inspection of the graph reveals that some of the highest figures for *AS* at Gjöahavn are represented at Potsdam by the figure 3, and thus correspond to figures which, according to Gjöahavn, indicate much less disturbed days. This may, however, be due to the geographical situation of the two stations.

After the above was written we received from Dr. van Dijk a paper,[4] which contains the international character-numbers for 1904. Without changing my original text I only add the curve for these figures at the bottom of Figure 2. Comparing *AS* for Gjöahavn with the curve for these international character-numbers, it is seen that the parallelism here is still more striking.

Figure 3 contains a graph showing monthly mean values for diurnal variation of storminess for *D*, *H*, and *V* at Gjöahavn for the year 1904.

[4]Caractère magnétique des années 1890-1905, De Bilt, (1938).

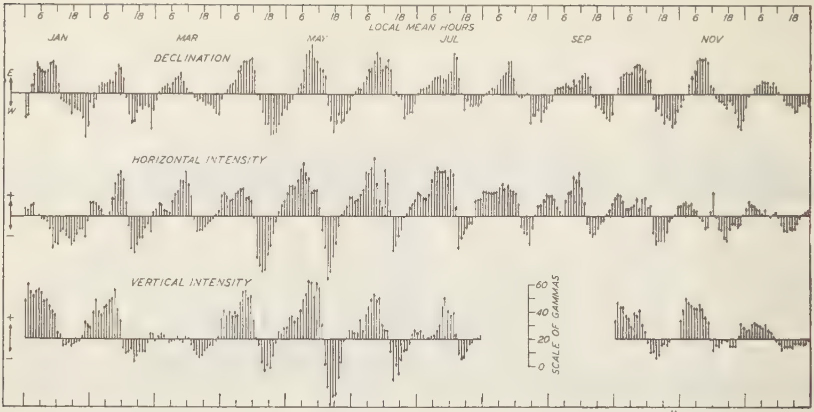


FIG. 3—MONTHLY MEAN VALUES DIURNAL VARIATION OF STORMINESS FOR D, H, AND V, GJÖAHAVN, 1904

In this graph, we note the beautifully developed diurnal wave in all the three elements. This is especially remarkable because it shows the conditions at a station in the immediate neighborhood of the north magnetic pole.

Det Magnetiske Byrå,
Bergen, August 1938

THE NON-MAGNETIC R. R. S. *RESEARCH*

By J. A. Edgell

Readers of this Journal have learned from brief notes published from time to time, that a non-magnetic vessel, the *Research*, is being built by the British Admiralty to continue the magnetic survey of the oceans inaugurated by the Carnegie Institution of Washington through its Department of Terrestrial Magnetism and carried on by the non-magnetic vessel, *Carnegie*, from 1909 until her destruction by explosion and fire in November 1929. It is especially fitting that Great Britain should assume the responsibility of continuing this important work in view of her great maritime interests. For many years the magnetic charts issued by the hydrographic services of the various countries have been based in increasing degree on data obtained by the *Carnegie*, but serious gaps in available data which would have been filled had she completed her last cruise, and the absence of information regarding the secular change in certain regions render imperative the resumption of the interrupted oceanic survey both from theoretical and practical considerations.

To remedy this condition, the construction of the *Research* was authorized over three years ago but the keel was not laid until September 9, 1937. Since that time good progress has been made. In order to assist in designing the vessel and her instrumental equipment, the Carnegie Institution of Washington, upon invitation of the Admiralty, made arrangements that William J. Peters, first commander of the *Carnegie* and designer of many of the special and improved types of magnetic instruments used at sea, spend a year in London as consultant on the design of the new vessel and of her special instruments. In addition all information regarding the *Carnegie* was placed at the disposal of the British Admiralty, thus facilitating greatly the design of the new vessel.

The *Research* (see Figs. 1 and 2) is being built by Philip and Son, Ltd., Landquay and Noss Engineering Works, Baltic House, Leadenhall Street, E. C. 3, London, England. The construction of such a non-magnetic vessel obviously presents many problems to the builder who must substitute bronze, brass, and other non-magnetic metals for all magnetic materials. One of the chief difficulties encountered has been the exclusion of iron and steel from the auxiliary Diesel oil-engines manufactured by Messrs. Petters of Yeovil. These are 160 horse-power, four-cylinder, two-stroke, direct air-reversing engines driving a two-blade feathering propeller. The difficulty has been solved by the extensive use of a bronze alloy, the crank shaft being made of a special non-magnetic steel. Besides the main Diesel engines, there are two of 9 horse-power and one of 18 horse-power, for the dynamos, refrigerator (cold storage 120 cubic feet), air-compressor, and winch for oceanographical work. The 160 horse-power Diesel engines will develop a speed of 6-1 2 knots, and the oil capacity of 14 tons is sufficient for

3,000 miles of travel. Electric current will be developed by two 4-kilowatt 110-volt dynamos. How rigorously the non-magnetic requirements have been met is evident from the fact that such items as iron nails in packing cases, tin food- and cigarette-containers, cooking utensils, cutlery, razor blades, drums for paint and lubricating oil, typewriters, etc., have been subjects of careful consideration.

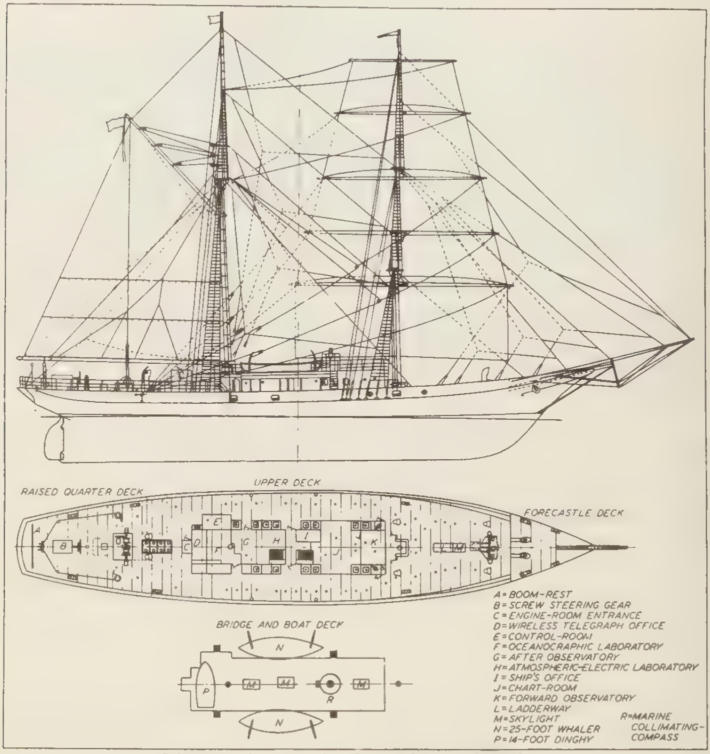


FIG. 1—DECK PLAN AND SAIL ELEVATION, R.R.S. RESEARCH

SCALE IN FEET

0 30 60 90 120 150

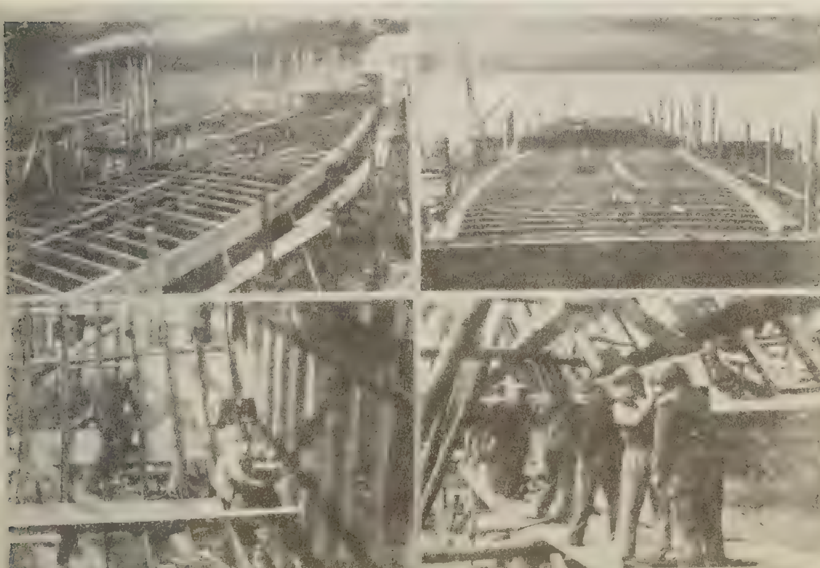
The vessel is 142 feet 6 inches on the water-line and has a moulded breadth of 34 feet, a maximum draught of 13 feet 2 inches, and a load displacement of 770 tons. She will be brigantine rigged and will have a full sail area of about 12,000 square feet. The deck-plan and sail elevation are shown in Figure 1; it is to be noted that the final design of rig and rigging is not complete.

The keel, stem, and stern-posts are of teak, the false keel is of Canadian rock-elm, and teak planks are laid on brass frames subdivided by eight metal water-tight bulkheads. The hull is sheathed with copper. The ballast consists of 80 tons of lead, 20 tons on the keel, and 60 tons

in the bilges. Anchors, cables, and wire for rigging are of aluminum bronze. Specially designed teak tanks for fresh water will have a capacity of 37-1/2 tons. Accommodation is provided for six officers, four scientists, and 22 petty officers and men.

In addition to two magnetic observatories, one forward and one aft, there will be two laboratories, one each for atmospheric-electric and oceanographic research.

The instrumental equipment for magnetic observations will include: For declination a marine collimating-compass of the original design by W. J. Peters and which was the standard instrument on the *Carnegie* (this instrument will be mounted on the bridge-deck over the chart-room); for determining the intensity of the force of the Earth's field, a marine deflector as designed by L. A. Bauer and J. A. Fleming of the Carnegie Institution of Washington; and for inclination a marine earth-inductor likewise of the design of the Carnegie Institution of Washington. A Smith portable magnetometer, a CIW magnetometer-inductor, and a dip-circle will also be carried for observations on shore and for instrumental comparisons at observatories.



The instruments which will be used in the atmospheric-electric work include: A potential-gradient recorder, a point-discharge apparatus, and a Wulf electrometer for standardizing the potential-gradient observations; a modified Ebert apparatus for ion-counting; and a modified Wilson apparatus for determining the electrical conductivity of the atmosphere through measurements of the air-earth current.

The standard meteorological instruments for oceanic work will be provided to determine air-temperatures, air-pressures, dry- and wet-bulb temperatures, and sea-temperatures. An Assmann psychrometer and Aitken nuclei-counter will be carried. Echo-sounding apparatus will be mounted in the oceanographic laboratory and an oceanographic winch will be provided for securing water-samples, temperatures, etc., at different depths. This winch will be driven from the auxiliary engines through line shafting and a fluid flywheel.

It is expected that the vessel will be launched in February 1939 but that she will not be ready for her first voyage before October 1939. Her first port of call will be Washington, D. C., whence she will proceed to South America, cross the South Atlantic to Capetown, and then take up a double traverse of the Indian Ocean, calling at Perth, Cocos Island, Colombo, Seychelles, Mauritius, and Durban, where she is scheduled to arrive in November 1940. It is to be noted that extensive work in the Indian Ocean is planned during this first cruise, since, as shown by the results obtained by the *Carnegie*, the greatest uncertainty in the magnetic elements, prevails in that region.

Hydrographic Department, Admiralty,
London, England

AN ALTERNATING-CURRENT APPARATUS FOR MEASURING SMALL MAGNETIC MOMENTS

By E. A. Johnson and A. G. McNish

Abstract—A method of measuring the moments of small magnetic dipoles is described. The dipole to be measured is rotated inside of a fixed coil, and the voltage induced in the coil is measured by means of an alternating-current amplifier. The limiting sensitivity is computed from the calculated signal-voltage and the thermal agitation in the input-circuit. In the practical application the theoretical sensitivity is approximately obtained and moments of 3×10^{-7} CGS unit can be detected and with a specimen 1.5 cm on a side 8×10^{-8} CGS unit/cc can be detected. The method has been applied to the measurement of the polarization in sedimentary deposits.

General considerations

One of the most important problems of terrestrial magnetism is that of the origin of the secular variation. However, the observed data available for the study of this question are for the most part too scanty, principally because they cover too short a period. To extend the data numerous attempts have been made to correlate the permanent magnetic polarization in various types of geologic formations with the Earth's magnetic field at the time the formations were laid down. By this means it has been hoped to extend the measurements of declination, inclination, and even of intensity back through prehistoric time. These attempts have met with varying success both because of experimental difficulties and because of difficulty of interpreting the data. The complexity of the phenomena of magnetic polarization in rocks and the difficulty of their interpretation have been discussed by Koenigsberger.[1] His recent articles in this Journal are accompanied by a comprehensive bibliography, which has been used in this paper; consequently many of the references will not be repeated here.

Because of the difficulty of interpretation in both sedimentary and eruptive rocks, due to the effects of heating, chemical action, pressure, movement, and other phenomena occurring during metamorphosis, it seemed[2,3] promising to investigate the polarization of non-metamorphozed sediments, using an apparatus of high sensitivity to measure the small magnetic moments expected. The apparatus described below was used in this investigation and has exhibited more than ample sensitivity.

In investigating the moment of a specimen of very weakly polarized material it is essential to accuracy that the specimen shall not be subject to any thermal, mechanical, or magnetic shock. For these reasons an electrodynamic method of measurement has several advantages[4,5,6,7].

In an electrodynamic method the specimen is rotated or translated with respect to a system of coils and the induced voltage detected by

[1] J. G. Koenigsberger, Terr. Mag., 43 119-130 and 299-320 (1938).

[2] A. G. McNish, Terr. Mag., 43, 283-284 (1937).

[3] E. A. Johnson, Rev. Sci. Instr., 9, 263-266 (1938).

[4] R. Chevallier, Ann. Phys., Paris, 4, 5-162 (1925).

[5] M. G. Grenet, C.-R. Acad. Sci., 196, 874-875 (1933).

[6] E. Thellier, C.-R. Acad. Sci., 197, 232-234 (1933).

[7] F. Krüger and F. Brasack, Ann. Physik, 30, 113-135 (1937).

some suitable electrical meter. One particular advantage is that the specimen is not subjected to any demagnetizing forces during measurement, and may be measured in fact in a field-free space by neutralizing the Earth's magnetic field.

The use of an alternating-current method of detection has particular advantages in respect to sensitivity and avoids as well the inaccuracies of a magnetometric method.

Theory

In the following analysis it is assumed that the specimen under test can be considered to be a dipole, and that it is being rotated at a frequency of f revolutions per second at the center of a circular coil, the cross-section of which is shown in Figure 1 together with a block-diagram

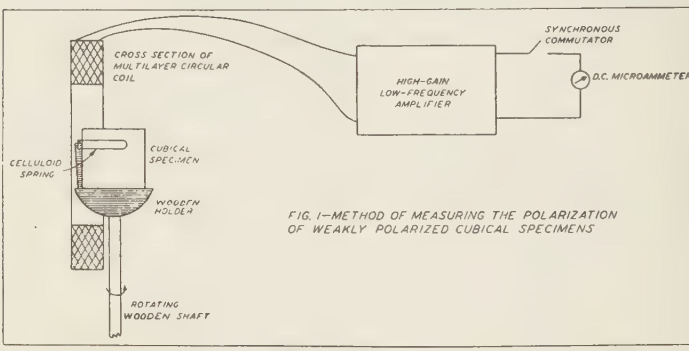


FIG. 1—METHOD OF MEASURING THE POLARIZATION OF WEAKLY POLARIZED CUBICAL SPECIMENS

of the circuit. The dipole is perpendicular to the axis of rotation, which is along a diameter of the coil.

If the width of the coil l is small, the flux-linkages per turn of wire at a radius r when the dipole is perpendicular to the plane of the coil is given by equation (1).

$$\phi_r \cdot 1 = \int_r^\infty (M/r^3) \times 2\pi r \mathrm{d}r = 2\pi M/r \tag{1}$$

The flux-linkages for the turns from r_1 to r_2 are given by equation (2)

$$\Phi N = (\pi^2 lM/2a)\int_{r_1}^{r_2} (1/r)\mathrm{d}r = (\pi^2 lM/2a) \log (r_2/r_1) \tag{2}$$

where a is the circular area of the wire used in winding the coil. If at a time, t, the dipole is at an angle $\theta = 2\pi ft$

$$\Phi N(t) = [(\pi^2 lM/2a) \log (r_2/r_1)] \cos 2\pi ft$$

The root-mean-squared voltage induced in the coil at a constant frequency of rotation is given by equation (3).

$$e = (\pi^3 lMf \times 10^{-8}/\sqrt{2}a) \log (r_2/r_1) \tag{3}$$

The statistical voltage[8] produced in the input of an amplifier of bandwidth W, in which the first tube has an equivalent noise-resistance R_t and the circuit-resistance in the first grid is R_c, is given by equation (4).

$$E_n = 12.7 \times 10^{-11} \sqrt{W(R_t + R_c)} \qquad (4)$$

where the coil-resistance R_c is given by

$$R_c = (\pi^2 l \rho / 4a^2)(r^2_2 - r^2_1)$$

and ρ is the conductivity of the wire used in winding the coil.

Then the signal-to-noise voltage is given by equation (5).

$$(e/E_n) = 1.68 \times 10^{-8}\, lfm \log (r_2/r_1) / \sqrt{W[R_t a^2 + (\pi^2 \rho l/4)(r^2_2 - r^2_1)]} \qquad (5)$$

Having chosen r_2 and r_1 it can be seen that this ratio increases with a decrease in a—the area of the wire used in winding the coil—up to the point where the coil-resistance is large compared to the resistance R_t. For the best tubes[8, 9] R_t lies between 3,000 and 20,000 ohms so that the coil should be wound with enough turns of fine wire so that the coil-resistance exceeds R_t by a factor of at least three or four.

When the requirement of many turns is met the signal-to-noise ratio is given by equation (6).

$$(e/E_n) = [1.07 \times 10^3\, l^{1/2} fM \log (r_2/r_1)] / [W\rho\, (r^2_2 - r^2_1)]^{1/2} \qquad (6)$$

By inspection it is seen that this has a maximum value when $r_2 \simeq r_1$, that is, when the coil-depth $(r_2 - r_1)$ is as small as practically possible in complying with the condition that the coil-resistance $R_c >> R_t$.

For a synchronous commutator, the smallest signal-voltage[10], e_m, that can be detected in the presence of a pure statistical voltage E_n is given by

$$e_m = [\sqrt{5\lambda / W}]\, E_n \qquad (7)$$

where λ is the time-constant of the output-meter.

The smallest moment that can be just detected is from (6) and (7)

$$\triangle M = 2.8 \times 10^{-6} [\lambda (r^2_2 - r^2_1)/l]^{1/2} / f \log (r_2/r_1) \qquad (8)$$

assuming $\rho = 1.8 \times 10^{-6}$ ohm-cm.

In order to obtain the limit of sensitivity it is necessary to minimize external disturbances. This is done at the expense of a small reduction in the sensitivity by winding a number of turns on the same coil-form but with a larger mean diameter and in the opposite direction to the signal-winding, and with enough turns so that the net induced voltage, due to fluctuating external fields which are approximately uniform over the area of the two coils is zero. Such disturbing magnetic fields are fluctuations in the Earth's magnetic field or in magnetic fields due to power-currents.

If the radii of the neutralizing coil are r_3 and r_4, equation (8) becomes

$$\triangle M = 2.8 \times 10^{-6} [\lambda (r^2_4 - r^2_3 + r^2_2 - r^2_1)/l]^{1/2} / f \log (r_2 r_3 / r_1 r_4) \qquad (9)$$

[8] E. A. Johnson and C. Neitzert, Rev. Sci. Instr., 5, 196-200 (1934).

[9] G. L. Pearson, Physics, 5, 233-243 (1934).

[10] E. A. Johnson, to be published soon.

The reduction in sensitivity due to the neutralizing winding is small in any practical case.

In the apparatus described below the dimensions of the coil and the constants of the amplifier were:

$r_1 = 1.9$ cm	$l = 1.5$ cm
$r_2 = 4.1$ cm	$f = 10$ cps
$r_3 = 4.1$ cm	$W = 10$ cps
$r_4 = 5.1$ cm	$\lambda = 0.02$ sec^{-1}

From (9) the limiting sensitivity is 2.8×10^{-7}CGS unit.

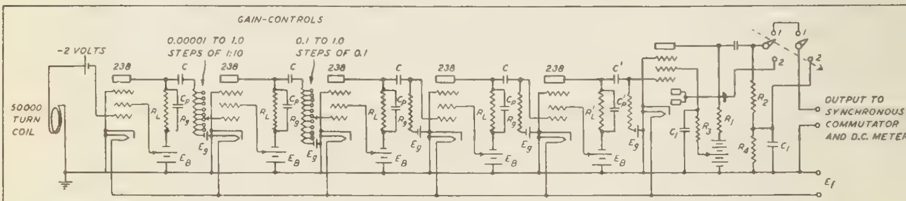
With this size of coil a specimen of 1.5 cm on a side may be used and polarizations of 8×10^{-8} CGS unit/cc can be detected. If a coil of the same relative dimensions and ten times as large were used, the sensitivity would be 8×10^{-11} CGS unit/cc. In order to measure the polarization to $\pm$ 2 per cent the signal-voltage must be approximately 25 times the minimum detectable signal. For the dimensions of the small coil 2×10^{-6} CGS unit/cc should be measurable to ± 2 per cent and it should be possible to determine the direction of polarization to $\pm 1°$.

Apparatus

A resistance-capacity tuned amplifier[11] was used with its resonant frequency at 10 cps. Although from (9) it is evident that the limiting sensitivity is independent of band-width, it is desirable to tune the amplifier in order to reduce any effect of parasitic voltages such as those due to 60-cycle pickup, etc., and to avoid overloading of the amplifier. The circuit-diagram of the amplifier is given in Figure 2.

The specimen to be measured is clamped on top of a rotating shaft against a wooden guide by means of springs of celluloid. All parts of the rotating holder were carefully tested for susceptibility to eliminate

[11]E. A. Johnson, Physics, 7, 130-132 (1936).



CIRCUIT-CONSTANTS

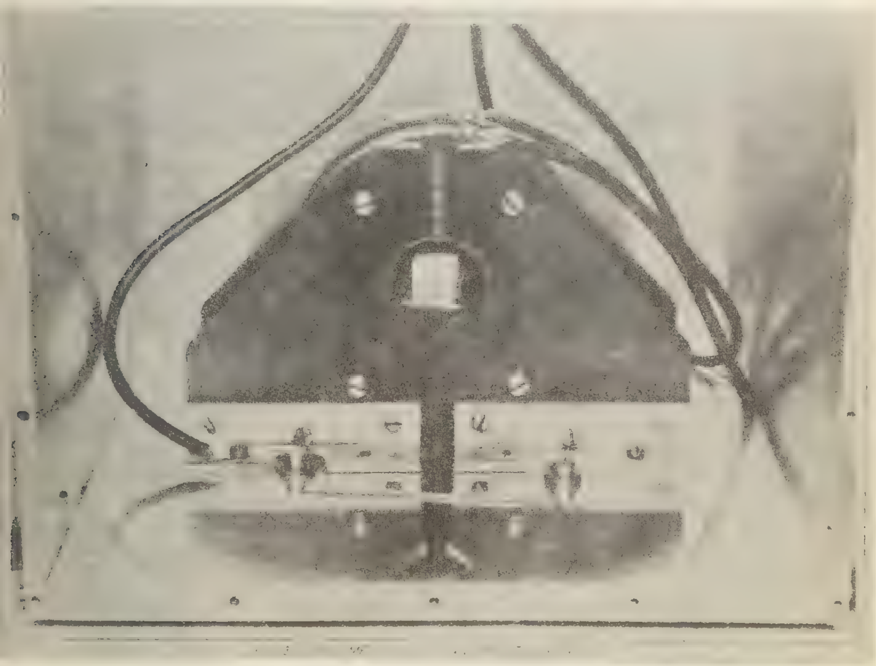
R_L = 300 000 OHMS
R_g = 1 000 000 OHMS
R_L' = 100 000 OHMS
R_g' = 300 000 OHMS
R_1 = 250 000 OHMS
R_2 = 500 000 OHMS
R_3 = 1 MEGOHM
R_4 = 500 000 OHMS
C_1 = 1 MICROFARAD
E_g = −1.5 VOLTS
E_B = +28.5 VOLTS
E_{SG} ADJUSTED SO THAT $I_p \cong 45$ MICROAMPERES
E_B' = 135 VOLTS
E_g' = −1.5 VOLTS
E_f = 6 VOLTS

VALUES OF C AND C_p FOR TUNING

f_0	C	C_p	C'	C_p'
CPS	MMFD	MMFD	MMFD	MMFD
1	0.15	0.77	0.50	2.4
10	0.015	0.077	0.050	0.24
100	0.0015	0.0077	0.0050	0.024
250	0.00060	0.0031	0.0020	0.0096
500	0.00030	0.0016	0.0010	0.0048
1000	0.00015	0.00077	0.00050	0.0024
2000	0.000075	0.00039	0.00025	0.0012

FIG. 2—HIGH-GAIN AMPLIFIER

parasitic effects caused by unsymmetrical induction in the Earth's field. The wooden parts of the holder and the shaft are made cylindrically symmetrical with respect to the axis of rotation. The phosphor-bronze shaft was also made carefully concentric with the axis of rotation to eliminate the effects due to eddy-currents which would cause a fluctuating magnetic field if the rotating conducting parts were cylindrically unsymmetrical. A photograph of the holder and coil are shown in Figure 3.



The coil is wound on a thick bakelite form and is supported by a rigid bakelite frame which is fastened to a one-half inch aluminum base. The entire coil-assembly is enclosed in an aluminum box, which is rigidly fastened to a pier of non-magnetic baked brick. The rigid construction is designed to minimize the effect of small vibrations of the coil transmitted through the pier from the rotating shaft. In an unneutralized coil a vibration of 0.001 second would cause a detectable zero due to the Earth's field. With the coil-winding used considerably larger vibration-amplitudes may be tolerated.

The coil itself is shielded electrostatically by a thin layer of aluminum foil which encloses the entire coil. This was found to be necessary since in the absence of this shield the electrostatic charges carried around on the wooden holder, the celluloid spring, and perhaps on the specimen introduced a spurious voltage of considerable magnitude and varying amplitude. By the use of a coil neutralized against external disturbances,

of diamagnetic wood and celluloid for the rotating holder, and of proper electrostatic shielding and grounding, all pickup from power-lines and all parasitic voltages have been eliminated. Thus, even for the highest sensitivity the measurements are reliable and reproducible. This is of the utmost importance when it is realized that parasitic voltages of the order of 10^{-7} volt may seriously affect the measurements.

The vertical phosphor-bronze shaft rotates in the hollow center of the pier and is driven by a horizontal phosphor-bronze shaft about 30 feet long. A synchronous alternating-current motor is used as a source of driving power. The neutralizing winding on the coil eliminates the disturbance from the alternating-current field of the motor.

A synchronous commutator is driven by the same shaft and the output of the amplifier is fed into it in series with a sensitive micro-ammeter whose period is adjustable.

Method of measurement

To measure a cubical specimen it is placed in the holder and the deflection of the output-meter is adjusted to zero by varying the phase of the commutator and the phase is recorded. The phase is then changed by 90° and the maximum is recorded. This is done for the three axes of rotation. The amplifier- and coil-assembly are calibrated in magnitude and phase by replacing the specimen by a standard magnet of known moment and with its azimuth known with respect to the planes of the guides on the holder. This is necessary since a high-gain amplifier does not remain sufficiently constant over long periods of time to give the desired accuracy.

A typical test-curve is shown in Figure 4, in which the meter-reading is plotted against the phase of the commutator. The two sets of points indicate the reliability with which results may be duplicated.

The predicted sensitivity 3×10^{-7} CGS unit was readily realized without any parasitic voltage using a meter-constant of $\lambda=0.02$ sec^{-1}.

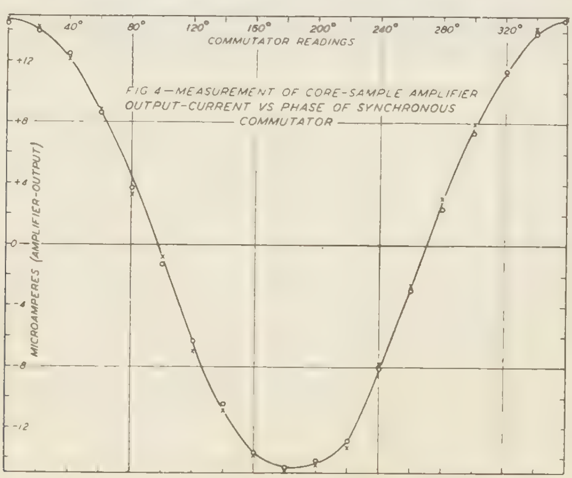


FIG 4—MEASUREMENT OF CORE-SAMPLE AMPLIFIER OUTPUT-CURRENT VS PHASE OF SYNCHRONOUS COMMUTATOR

Most of the observations have been made with the period of the output-meter adjusted to about ten seconds, since in the problems studied the ultimate sensitivity has not been required.

It would be possible to increase the sensitivity about 50-fold by increasing the frequency of rotation 50 times. Such a high sensitivity has not been necessary in the present investigation and has several mechanical disadvantages.

In the investigations reported in the following paper, the direction of magnetization has been most thoroughly investigated, since it was felt that the intensity had a too complex and uncertain relation to the original intensity of the Earth's field at the time of deposit, to be readily interpreted, whereas the direction of magnetization might more reasonably be expected to remain unchanged. In regard to phase it was found that the phase-shift in the amplifier was negligible over several days, that is, less than 1°, and measurements of the standard magnet could be repeated to within 1° during that time.

It is a pleasure to acknowledge the support of Dr. J. A. Fleming in this work. Thanks are also due to V. Vacquier who first suggested the method of measurement.

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(See also page 408)

36. *German Geophysical Society*—The annual meeting of the German Geophysical Society, under the presidency of J. Bartels, Potsdam, was held in Jena, October 19 to 22, 1938. The meeting opened with a visit to the establishment of Carl Zeiss where an exhibit accompanied by projections of films was viewed.

The scientific sessions were held in the auditorium of the Physikalische Anstalt. The third session, held October 21, was devoted to papers on terrestrial magnetism, polar lights, ionosphere, and cosmic radiation. Among the papers presented were the following: G. Fanselau, Geophysikalische Arbeiten Professor Filchners in Inner-Asien; T. Schlomka, Zur Elektrodynamik des rotierenden Erdmagneten; J. Bartels, Besprechung erdmagnetischer Registrierungen im Hinblick auf Vorgänge in der Ionosphäre und Wirkungen in der Höhenstrahlung; F. W. P. Götz, Zum Nordlicht vom 25. Januar 1938; N. N., Ionosphärenuntersuchungen mit reflektierten Wellen; W. Kolhörster, Intensitätsschwankungen der Höhenstrahlung im Zusammenhang mit erdmagnetischen Variationen; H. Rudolph, Die negative Aufladung der Ionosphäre der Erde.

On October 22, the four following papers were given bearing on terrestrial magnetism and electricity: R. Bock, Ueber die Magnetische Reichsvermessung; G. Fanselau, Ueber die Eignung einiger ferromagnetischer Legierungen zu erdmagnetischen Messzwecken; R. Penndorf, Der Einfluss von Druck und Temperatur auf die Absorption von Wasserdampf und Ozon; J. Bartels, Einige Gezeitenerscheinungen im erdmagnetischen Feld und im Luftdruck.

37. *Notes on magnetic work of the United States Coast and Geodetic Survey*—Programs of improvements at the Cheltenham and Tucson magnetic observatories of the United States Coast and Geodetic Survey have been carried out under PWA grants. At Cheltenham, a new fire-proof storage building for magnetic instruments was constructed, an artesian well was drilled, a concrete apron and concrete foundations were placed under the test-laboratory, and miscellaneous repairs were made, in addition to acquiring new shop-equipment and several new instruments.

At Tucson, a new building for office, shop, storage, and dark-room is being erected. Repairs to the variation-observatory foundations were contemplated, but upon examination of the building, it was found that dry rot and termites had attacked the foundations so extensively that it was not feasible to make repairs. Instead, designs for a new variation-observatory are being prepared, and it is hoped that this new structure may be completed within a year or so.

Because of extensive building operations at Sitka as a result of the establishment of a Naval air-base at that place, the future of the magnetic observatory is seriously threatened. Plans have been made to test a proposed new site for an observatory at the Experimental Farm, now under the jurisdiction of the Forest Service, near Sitka. If a satisfactory site can be found and funds for the move are forthcoming, the new observatory should be free from any threat of artificial disturbance in the future.

MAGNETIZATION OF UNMETAMORPHOSED VARVES AND MARINE SEDIMENTS

By A. G. McNish and E. A. Johnson

Introduction—Knowledge concerning the range of its variation is essential to an understanding of the Earth's general magnetic field. Clearly, if, as some claim, the Earth's magnetic field has been completely reversed in past geologic ages our notions of its origin, and perhaps our entire conception of the Earth's interior, must be radically revised. On the other hand, if it can be shown that the Earth's general magnetic field is a rather static phenomenon and that the observed secular changes involve only a superficial portion of the field other types of causes are suggested.

Direct observations of secular variation extend over four centuries at a few places on the surface of the Earth. Although some of the changes have been very large they suggest cyclic variations rather than continuous variations in one direction. Some of the more remarkable of these changes are a shift in declination from 11° east to over 24° west at London from 1600 to 1800, a decrease of 5900 gammas in horizontal intensity at Capetown from 1843 to the present time, and a decrease of 6000 gammas in vertical intensity off the Guinea Coast from 1885 to 1922. If changes as great as these have occurred in modern historic times how great have the changes been in thousands and millions of years of prehistory?

Attempts have been made to solve this problem by study of the magnetization of rocks. An extensive bibliography on the subject has been given by Koenigsberger [see 1 under "References" at end of this paper]. These researches have proceeded in accordance with the hypothesis that igneous rocks, cooling through the Curie point, assume polarity coincident with the direction of the Earth's magnetic field at the time and place of their formation. Thus, by measuring the magnetic polarization of a specimen and referring its direction to the geographic direction of the specimen *in situ* a record of the magnetic declination and inclination at the time of formation should be obtained. Measurements of specimens from lava-flows of recent geologic age have indicated that the Earth's magnetic field has been completely reversed, that is, the dip-needle once pointed upwards where it now points downwards. Similar measurements made on clays which have been baked by overrunning of hot lava have also indicated such reversals of the Earth's field.

How faithfully the residual magnetization of lavas or clays baked by the lavas may represent the direction of the Earth's field at the time of their formation remains open to doubt. Blocks of lava may cool below the Curie-point and may be turned over a number of times before attaining their final positions of repose. The reported reversed magnetization of metamorphosed clays does not seem explicable on such a basis. However, the implications of these results are so important that extensive research in the magnetization of rocks is desirable.

Renewed attack of this problem has been facilitated by the recent

development of a sensitive electromagnetic method for measuring the residual polarization of rocks. The particular virtue of this method is its ability to obtain accurate values even when the polarization is extremely feeble. Furthermore, in the process of making the observations the specimens are never submitted to a greater demagnetizing force than the Earth's natural field [2, 3].

Description of sediments—The measurements to be described in this paper were conducted on unmetamorphosed deposits of recent geological age. These materials were selected for several reasons: (1) Since formation these deposits have retained a constant position; (2) an accurate relative dating can be worked out in most cases; (3) they may be collected and prepared for measurement without being submitted to any great mechanical strain; (4) the probability that their connate magnetization has been altered by thermal, mechanical, or chemical agencies is a minimum; (5) variations in their residual magnetization may be compared with the progress of secular variation observed at the present time. Such deposits may have become magnetic by the directive force of the Earth's field acting on individual particles as they settle through water. If the settling takes place in quiet water and if the particles are small the magnetic axes of the particles should, on the average, be fairly closely aligned in the direction of magnetic declination; however, since it is likely that the magnetic axes may also be the longitudinal axes of the particles a slight systematic force exerted by their fall through water may tend to align them more horizontally than the magnetic inclination.

Two types of sediments have been examined so far—the varved Pleistocene clays left at the retreat of the last glaciation from New England and ocean-bottom sediments obtained by the core-sampler developed by C. S. Piggot of the Geophysical Laboratory of the Carnegie Institution of Washington [4]. At the present time results obtained from the varved clays must be regarded as the more significant.

The varved clays are admirably adapted for this study. They are composed of material washed into ancient glacial lakes by seasonal melting of the ice. Larger particles, such as grains of sand, settle during the summer, and finer particles settle during the winter when the lakes are frozen over and their waters in a very quiet state. The winter and summer layers are readily distinguishable, the former being extremely impervious and of a "greasy" texture while the latter are porous and granular. This difference in porosity is strikingly revealed in weathered exposures of the varves; water frequently seeps through the summer portions and much of the material near the face of the exposure is eroded away, leaving the winter portions protruding and drooping over the edge like shingles on a roof.

Accurate dating of the varves with respect to an arbitrary time-scale is possible because of the extensive researches of Antevs [5]. Due to different meteorological conditions and possibly other factors the quantity of material deposited each year varies, the thickness of individual varves in the series measured ranging from a few millimeters to several centimeters. Measurements on the thickness of the individual varves plotted in succession are compared with the "standard" plots prepared by Antevs, and thus a date can be assigned to each varve referred to the Year 1 of Antevs' chronology (see Fig. 1).

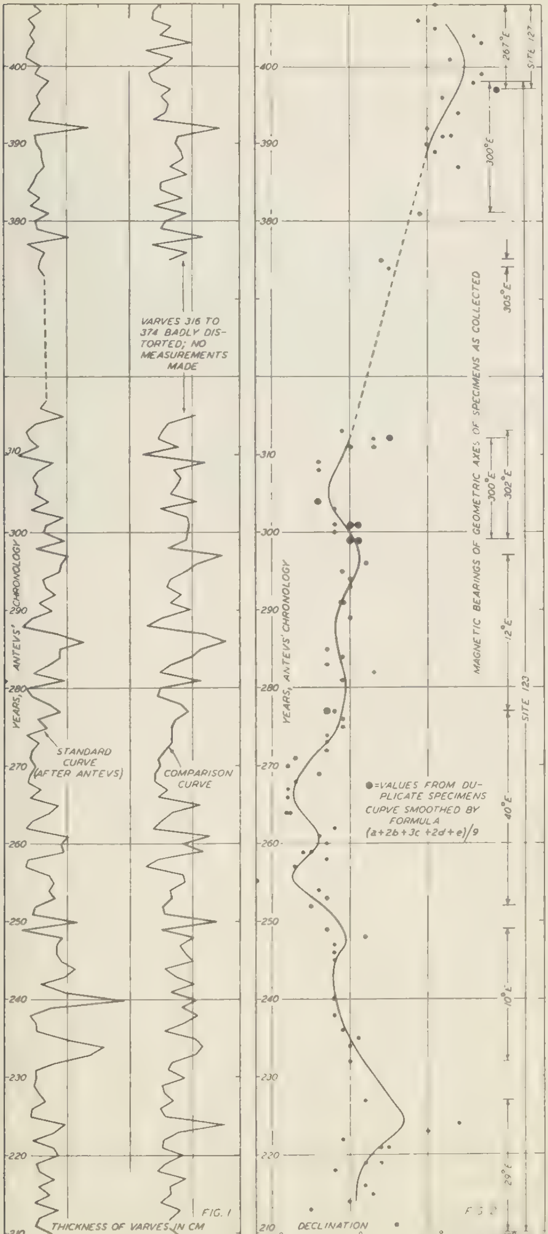

FIG. 1—THICKNESS OF VARVES USED FOR MAGNETIC MEASUREMENTS COMPARED WITH STANDARD CURVE OF THICKNESS

FIG. 2—DIRECTION OF MAGNETIC POLARIZATION OF VARVES REFERRED TO PRESENT DECLINATION

Procedure—Specimens were removed from the clay banks for magnetic tests following the method employed by Antevs, special precautions being taken to avoid magnetic disturbance. First a perpendicular surface was obtained in pits where large quantities of the clays had been excavated for the manufacture of bricks. Iron tools were used for rough work to penetrate far enough into the bank to assure freedom from the magnetic effects caused by steam-shovels used in excavation, and then a smooth surface was produced with a sheet of brass. Brass troughs 24 inches long, three inches wide and two inches deep, were forced or driven into the banks, the contiguous material removed, and the clay contained by the trough cut free with a sheet of brass. Before removing the trough its bearing with reference to the prevailing magnetic declination was determined with a pocket-compass mounted on a brass bracket. Troughs of clay were collected at various depths, some over-lap of the troughs being allowed to assure continuity of the series. Collections were made from the sites at New Haven, Connecticut, designated by Antevs as No. 127 and No. 123, about 2.5 miles apart.

After collection the specimens were brought to the laboratory in Washington, permitted to dry out partially, and then cut into cubes for magnetic tests. The cutting was performed with a diamond saw constructed for the purpose. All proximity to strong magnetic fields was avoided. The prepared cubes were shellacked since it had been found that no changes in magnetic properties resulted from this treatment. The geometric axes of cubes cut from different troughs bore different relations to the magnetic direction *in situ* as troughs were removed from banks at various angles to each other. This assured that the specimens had not been subjected to any systematic influence which might have affected their magnetization during removal or subsequently.

Results—Measurements made on varves from the year 211 to the year 408, Antevs' chronology, showed an average magnetic polarization nearly 30° west of the present declination (see Fig. 2). Extreme ranges for individual varves ran from 11° west to 42° west. The maximum departure from present declination for the smoothed curve was about 35° around the year 265 and the minimum departure was about 15° around the year 400. Departures from the smoothed curve for individual varves, although the measurements are repeatable, do not necessarily represent real differences in magnetization as referred to the present declination. In only two cases do such differences exceed 5°. In view of the plastic nature of the clay and the difficulty of cutting it into true cubes, all having their sides parallel, the uniformity of the results is satisfactory. Magnetic measurements on all the varves collected was not possible as some of them crumbled in cutting. No significant difference was found in the direction of polarization of the several troughs, except for a gradual trend in spite of the large differences in bearing of their geometric axes. In those cases where cubes from the same varve were cut from different troughs good agreement was obtained, even when the troughs were taken from widely separated sites.

One of the cubes measured consisted almost entirely of a concretion of the original material. Its polarization differed from the smoothed curve by only 5°. Although this one sample is not adequate for drawing conclusions it suggests that formation of concretions does not alter the direction of magnetization of the original sediment.

Consistent differences were found in the direction of polarization of the portions of the varves deposited during summer and during winter. The average difference of direction for 26 pairs of cubes cut from the two portions amounted to 5°, the summer portions being magnetized more nearly in the present magnetic declination. Only one cube cut from the summer portion of a varve showed a greater departure from the present declination than the cube cut from the winter portion of the same varve. Since the summer layers are more porous than the winter layers such differences may be attributed to the action of water which may realign the particles in the summer layers. For this reason the winter layers are believed to be the more likely representatives of original magnetism and therefore have been used throughout.

The ocean-bottom sediments used in this investigation were supplied by C. S. Piggot. They were in the form of cores two inches in diameter and about eight feet long. Since they were not obtained primarily for magnetic measurements no special precautions against magnetic contamination had been observed in obtaining them or in subsequent handling. The core-sampling apparatus [4] consists of a long steel bit, containing a brass sleeve, which is driven into the ocean-bottom by a specially devised gun. The entire apparatus is lowered to the bottom where it is automatically discharged, driving the bit vertically into the sediment. The bit containing the brass sleeve, which is thus filled with bottom-sediment, is withdrawn and hoisted back on ship. The brass sleeve and the contained material are split longitudinally and then permitted to dry, eventually supplying a fairly consistent solid.

Of the several cores supplied only one proved suitable for magnetic measurements. This core was obtained from the North Atlantic in the Labrador Current. It consisted of a homogeneous material described as "blue mud." Since the core contained no glacial material it has been assigned entirely to post-glacial times, and probably represents from a thousand to ten thousand or so years of deposition. Cubes could be cut from it readily, as previously described; geometric directions of the cubes were referred to the vertical and to the plane along which the core was split. Obviously the directions could not be referred to magnetic declination of the present time, though consideration is being given to a method for doing this.

The direction of polarization in the horizontal plane was approximately the same at the top and bottom of the core but at a depth around 125 cm it averaged about 40° to the east of the top and bottom values (see Fig. 3). The inclination of the direction of polarization was also determined in the core. Its average value was about 50° and showed a trend similar to that exhibited by the declination, having a maximum value of about 60° where the declination was most easterly. The present value of magnetic inclination in the region from which the core was obtained is close to 80°.

Discussion of results--All of the varves exhibited magnetic polarization consistently different in direction from the present magnetic declination. In view of the various geographical alignments of the specimens the difference in direction of magnetization as compared with declination may not be attributed to artificial causes. Agreement of the results obtained from varves of about the same date but from two different sites separated by about 2.5 miles indicates that magnetic polarization

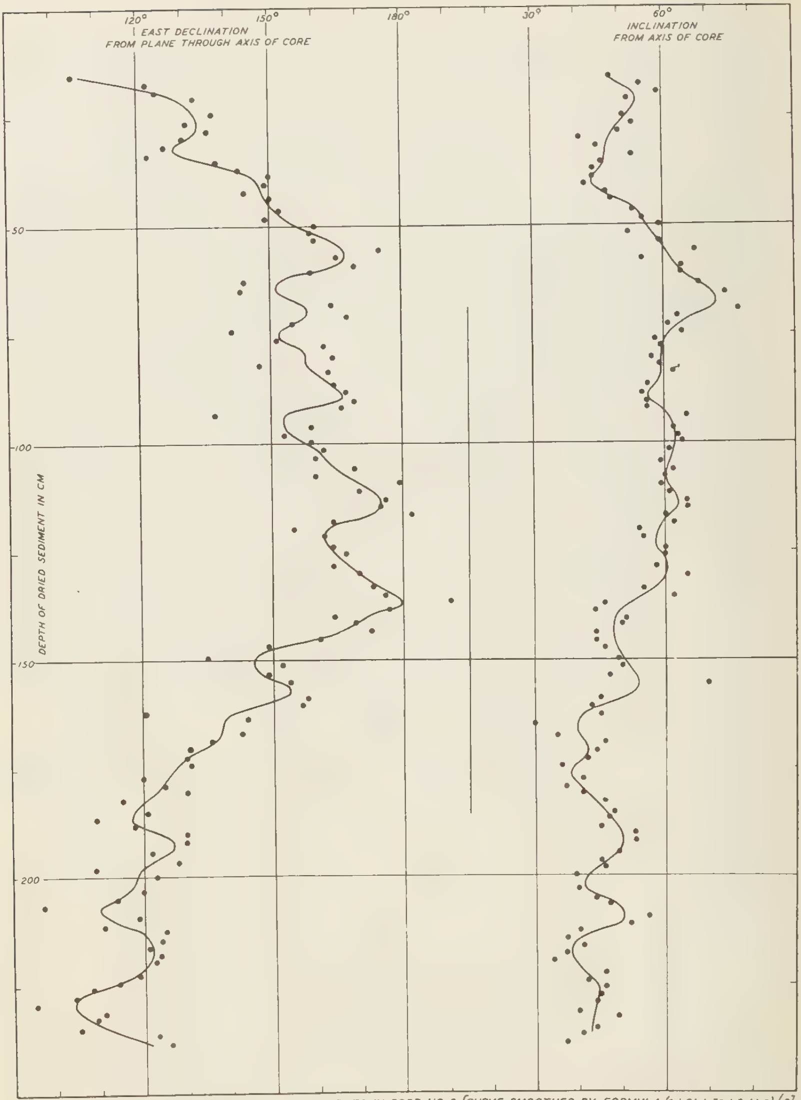

FIG. 3—DIRECTION OF MAGNETIZATION OF SEDIMENTS IN CORE NO. 3 [CURVE SMOOTHED BY FORMULA $(a+2b+3c+2d+e)/9$]

is a property which depends on time of deposition and which is uniform over large areas.

The difference of direction of magnetization of the summer and winter portions of the same varve is somewhat disconcerting. A reasonable explanation for this discrepancy is found in the greater porosity of the

summer layers making them more susceptible to the action of ground-water which may realign the grains of material. The winter-summer discrepancy appeared to be least for varves taken from the greatest depths where the flow of ground-water was least. This proffered explanation finds further support in the fact that the direction of magnetization of the summer layers exhibited regression toward the present value of declination.

The change in average direction of magnetization from about the year 265 to about the year 400, amounting to over 20°, is too great to be attributed to random or systematic errors of observation. Both the rate and total range of this variation are consistent with the secular variations which have occurred at a number of places on the Earth since the advent of magnetic observations.

Since the marine sediments were not obtained under the same ideal conditions as the varves, measurements on them must be considered with some reservation. No factor in securing the specimens seems adequate to account for the observed differences in direction of polarization. Greater significance could be attached to the measurements if they had been verified by measurements on other cores from the same region where the rate of deposition was the same, but so far no such cores have been available.

The marine sediments offer one advantage in discussion, namely that they have been kept at essentially the same conditions of temperature, pressure, and water-saturation from the time of their formation until their removal. There was no evidence of chemical change in the core tested. It is difficult to imagine that the sediments have been subjected to any mechanical force other than the weight of the material above. The difference of the inclination of magnetization as compared with the present inclination of the Earth's field upholds the view that the particles do not completely conform to the inclination while settling.

To summarize, the direction of magnetization of the sediments examined is most easily explained as due to influence of the Earth's magnetic field at the time of formation. If this is true the sedimentary rocks preserve a record of secular variation covering a vastly greater time than man's brief existence on this planet. Until many more data have been obtained judgment must be withheld as to whether or not these measurements represent the direction of the Earth's magnetic field at the time the sediments were formed; it is the writers' opinion that they do.

References

[1] Terr. Mag., **43**, 119-130 and 299-320 (1938).
[2] E. A. Johnson, Rev. Sci. Inst., **9**, 263-266 (1938).
[3] E. A. Johnson and A. G. McNish, Terr. Mag., **43**, 393-399 (1938).
[4] Sci. Mon., **46**, 201-217 (1938).
[5] Amer. Geog. Soc. Res. Series, No. 11 (1922) and No. 17 (1928).

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(See also page 400)

38. *Wilhelmshaven Marine Observatory*—The magnetic service of the German Kriegsmarine was transferred in the autumn of 1936 from the Wilhelmshaven Naval Observatory to the Deutsche Seewarte in Hamburg. The results of the magnetic observations which heretofore have appeared in the "Veröffentlichungen des Marineobservatoriums in Wilhelmshaven" are now continued in the publication "Aus dem Archiv der Deutschen Seewarte und des Marineobservatoriums" beginning with Band 57, No. 6 (1937) which contains the results for 1932.

39. *Atmospheric-conductivity measurements in Poland*—The special conductivity-apparatus constructed by the Polish Meteorological Institute at Warsaw after the design of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington will not be used on the Polish stratosphere flight as originally proposed owing to lack of space in the gondola of the balloon. It will instead be employed to measure the atmospheric conductivity at the Polish mountain observatories Kasprowy Wierch (1988 m) and Pop Iwan (2022 m).

40. *Annual values for 1937 at De Bilt Observatory*—Dr. G. van Dijk communicated the following mean values of magnetic elements observed at De Bilt Observatory for the year 1937: D, 8° 11′.8 west; I, 67° 08′.4 north; H, 18228 gammas; Z, 43237 gammas; X, 18042 gammas; Y, -2599 gammas; F, 46924 gammas.

41. *Corrigenda*—In the issue of September 1938 corrections should be made as follows: Page 222, in eleventh and fifth last lines read "Figure 3" instead of "Figure 2"; page 223, in fourth last line read "Figure 2" instead of "Figure 3"; page 255, in fourth line of second paragraph read "density" for "desity"; page 307, in Figure 5 read "0.2, 0.4, 0.6, 0.8" for scale of Q_{nt} instead of "2, 4, 6, 8"; page 308, in tenth line read "during the consolidation of" instead of "consolidating" and in Table 1, second column, read "Skye" and "Bergell" instead of "Syke" and "Bergwell"; page 314, in twenty-third line read "Figure 11-*B*" instead of "Figure 10-*B*" and in twenty-fourth line read "Figs. 12, 13" instead of "Figs. 11, 12, 13"; page 335, in Table 1 the values in column "Horizontal intensity" should be multiplied by ten, thus "3140γ" instead of "314γ", etc.

42. *Personalia*—Professor *Ch. Maurain*, Director of the Institut de Physique du Globe, was elected President of the Astronomical Society of France, June 15, 1938.

Professor *Viktor F. Hess*, formerly professor of experimental physics at the University of Innsbruck, and later at the Physikalisches Institut, University of Graz, has joined the faculty of Fordham University.

Captain *George S. Bryan*, U. S. N., assumed the duties of Hydrographer of the Navy, August 23, 1938.

Dr. *Willis Ray Gregg*, chief of the United States Weather Bureau, died September 14, 1938, at the age of fifty-eight years.

Dr. *Otto Hilgard Tittmann*, superintendent of the United States Coast and Geodetic Survey from December 1, 1900 to April 15, 1915, died August 21, 1938, in Leesburg, Virginia, aged eighty-eight years.

Professor *Gustav Melander*, formerly director of the Central Meteorological Institute of Finland, died at Helsinki, August 25, 1938, at the age of seventy-eight years.

SUMMARY OF THE YEAR'S WORK, DEPARTMENT OF TERRESTRIAL MAGNETISM, CARNEGIE INSTITUTION OF WASHINGTON[1]

By J. A. Fleming

The year ended June 30, 1938 has been marked by energetic prosecution of experimental investigation and continued coordination and integration of various researches paving the way for more general formulation of geophysical facts. Good progress has been made in two major projects which open new fields of investigation and promise important advances. One of these is the completion of the Atomic-Physics Observatory (see Fig. 1) and the considerable progress in the installation of the electrical equipment. The electrostatic generator and tube are designed to operate at potentials exceeding five million volts and offer unique opportunity for further studies in the expanding field of nuclear physics—a field to which we must look for additional understanding of magnetic phenomena. The second project realized is the installation of the automatic multifrequency equipments for ionospheric measurements at both the Huancayo and Watheroo magnetic observatories. This equipment, developed at the Department, has the following characteristics: Ability to record successfully without interference from existing radio services; relatively uniform vertical radiation throughout the frequency-range; automatic interlocking of transmitting and receiving tuning; mechanical simplicity and uniform limits of precision and resolution. The stations at Huancayo and Watheroo operating continuously in conjunction with a somewhat similar equipment at the National Bureau of Standards station at Meadows, Maryland, should provide a much more complete survey of the upper atmosphere than has been previously possible. Results at the Kensington Experiment Station of the Department in Maryland, where the apparatus was tested, appear to have gone a long way toward settling the vexed question of the ionosphere and its refractive index for radio waves, an uncertainty heretofore restricting our ability to interpret ionospheric observations.

Magnetic investigations—The outstanding advances in magnetic investigations concern two distinct branches of the science: The rapidly varying external field and the slowly varying, so-called permanent field. A procedure was developed for separating the internal and external portions of a localized varying magnetic field observed at the Earth's surface without recourse to the use of spherical harmonics by assuming the Earth's surface to be an infinite plane and employing solutions of Laplace's equation appropriate to the case. This permits the hypothetical mapping of the magnetic field at various heights, from which cogent inferences may be drawn regarding the location of the processes giving rise to the magnetic effects. Further attention was devoted to the theory suggested in 1936 to account for auroral-zone features of magnetic disturbance and for the average characteristics of magnetic storms in polar regions.

Numerous measurements and important improvements in method were made to determine the magnetization of rocks. Extensive tests were made on several cores taken from bottom-deposits of the North Atlantic. One core taken off Newfoundland consists of a finely divided material known as blue mud. Changes in magnetic declination as

[1]For complete details of the work here summarized reference may be made to Year Book No. 37 for year 1937-38 of the Carnegie Institution of Washington (1938).

great as 90° and consistent through the core were measured. If these changes correspond to real changes in the Earth's magnetic field they exceed any which have been recorded in historic times, although they are not so great as to cast doubt on their reality. Changes as great as 36° in declination have been recorded at London during two centuries. It has been estimated that the core in question represents sediments deposited over several thousands of years.

Measurements made on a sample of varved Pleistocene clay from old glacial lakes near New Haven, Connecticut, showed that this clay was sufficient to permit analysis. Accordingly about 200 varves were collected in brass troughs with great care following the method employed by Antevs in developing the chronology of the deposits and with definite reference to the geographical and prevailing magnetic directions. Continuation of these researches promises results of fundamental importance to terrestrial magnetism and geology.

Conventional methods for interpreting geologic structures from magnetic anomalies produced by them at the Earth's surface were extended and more powerful techniques considered which were successfully tried in several hypothetical cases.

A world-map of secular-variation activity was constructed for the interval 1885 to 1922, showing isopors for the magnitude of the total-change vector, regardless of sign or direction.

The weekly American magnetic character-figures (C_A) for the seven American-operated observatories at Watheroo, Huancayo, Cheltenham, Honolulu, San Juan, Sitka, and Tucson were compiled with the cooperation of the United States Coast and Geodetic Survey and were published weekly through *Science Service*. Statistical examination of the data for the first year of this character-figure shows it to be a precise measure and to represent world-wide conditions with relatively high fidelity.

In connection with the various proposals for the adequate description of magnetic disturbances, there has been formulated a Potsdam Magnetic "Kennziffer" (K). Its main difference from existing international and American (C_A) character-figures is the division of the Greenwich day into eight intervals of three hours each. Such a shorter interval seems more suitable because of the difficulty experienced in ascribing a single figure to a day or a half-day in which the degree of disturbance may vary considerably; on the other hand, a further subdivision (hourly intervals) would add greatly to the labor involved without proportional gain to justify it. K consists of two figures; the first, varying from 0 to 9, indicates the highest amplitude in the deviations of one of the three magnetic-force components from a smooth diurnal variation, while the second indicates the form of the variations (pulsations, bays, storms). So far, the definition of K has been chosen so as to give a good characterization of the records of Niemegk Observatory; the experience gained there should advance discussions for an international code.

The average world-wide changes in the Earth's field during magnetic storms, additional to those present on magnetically quiet days, were investigated using extensive new data of the International Polar Year, 1932-33, in continuation of a study undertaken under the supervision of Chapman. The average characteristics of disturbance given by observation were shown to be in good qualitative and quantitative agreement with the world-wide atmospheric-electric current-system of magnetic

storms proposed by Chapman. If these electric currents flow in closed circuits in the atmosphere their height is deduced as roughly 100-150 km. The electric current-system proposed by Birkeland was shown to be inconsistent with observation in several important respects. In low latitudes of the Earth it is also possible that the storm-time variation is due mainly to an encircling ring-current in the equatorial plane, in which case its radius computed from the magnetic data was found to be about two to four times that of the Earth.

An investigation of the average characteristics of magnetic storms asymmetrical relative to the centered dipole of the Earth's magnetic field forms a sequel to the foregoing. Since magnetic disturbances appear with highest intensity in the region very near the auroral zone, the magnetic data were used to give a new and improved determination of the geographical position of this zone. The auroral-zone curve of terrestrial magnetism, in north polar regions, is oval, almost elliptical, and shows asymmetry relative to the centered dipole. It agrees roughly with the curve of maximum auroral frequency as derived by Fritz, except in regions where his auroral data were scanty.

Instrumental developments—The CIW induction-variometer for measuring time-variations in the vertical component in the Earth's magnetic field was kept in continuous operation by the staff of the Cheltenham Magnetic Observatory of the United States Coast and Geodetic Survey, and experience has proved the practicality and superiority of this instrument for use at observatories.

The design and construction of the coil-form of the new CIW primary standard for measuring the Earth's magnetic vector has been continued. The actual construction of the coil, the most difficult part of the standard, is now completed and the alidade and mountings for the coil are now under way.

In connection with the development of the alternating-current voltage-measurements from the rotating coil of the primary standard, the limitation of alternating-current voltage-measurements due to a statistical source in the circuit in which a signal-voltage is to be measured was calculated theoretically and was determined experimentally. It was found that the limit of measurement was not dependent on the band-width of the amplifier, as has been previously supposed, but depends only on the time of measurement and the amount of the statistical voltage. From the analysis it becomes evident that for a given circuit the use of alternating-current amplification yields no theoretical increase in sensitivity over direct-current methods of measurement, although in many particular problems alternating-current methods offer great advantages. This result has been applied in the case of the measurement of small magnetic moments as well as to the case of the primary standard. The analysis also applies in the case of the searchlight-experiment and has numerous other practical applications of general interest.

Some preliminary experiments were made with a flickering searchlight-beam for investigating the upper air. Although the experiments were not conclusive, the light scattered from low heights was measured and the method was shown to be practical.

Cosmic radiation—The investigation of a positive relationship of cosmic radiation with magnetic and other phenomena was continued. World-wide decreases of three to five per cent in daily means of cosmic-

ray intensity are found to be associated with changes in the Earth's magnetic field during two major magnetic storms; other magnetic storms of equal intensity occur with no appreciable cosmic-ray effects. Thus it appears that the entire current-system for the storm-time field of both types of storms cannot be located at the same distance above the Earth. A significant correlation between changes in daily means of cosmic-ray intensity for two stations separated 50° in latitude probably results from the mechanism responsible for the magnetic-storm effect. Statistical analyses of the cosmic-ray records obtained at Cheltenham and at Huancayo proved inadequate to establish a sidereal diurnal variation in cosmic-ray intensity.

Analysis of all available data from Cheltenham, Teoloyucan, Christchurch, and Huancayo shows that the major changes in the 10-day means of cosmic radiation are all world-wide. The correlation between the world-wide changes at different stations was found high enough to provide important information regarding their variation with latitude and altitude. It seems impossible to explain the annual waves found at these stations in terms of a solar magnetic moment.

Atmospheric electricity—Most of the investigations in atmospheric electricity done during the report-year pertain to agencies which affect the conductivity and thereby give rise to variations from time to time and place to place in the electric conduction-current from air to Earth in areas of fair weather.

Continuous registration of large, intermediate, and small ions, and the rate at which ions are formed in a very thin-walled vessel, was continued at Washington, first in a well-ventilated room in the Standardizing Observatory and later in a sealed room of the main building using two ionization-apparatus. In conjunction with these registrations, manual observations of the concentration of Aitken nuclei were also made. In the sealed room the contribution of nuclei and large ions from the human breath was studied.

Examination of the records obtained in the sealed room showed that the large-ion and small-ion content of the air responded to occupancy in a manner similar to that found from earlier work. It was also discovered that the ion-production as indicated by the measurements with the thin-walled chamber also shows response to occupancy, the ionization being smaller when the building is occupied than when it is vacant. This result, not explainable at present, requires further study.

By thickening the thin cellophane wall of one ionization-apparatus with paraffin while another remained uncoated, a comparison of the results thus obtained made it possible to derive the amounts of ionization contributed by the different types of radioactive radiations, cosmic radiation, and residual or wall ionization.

Ion-counters were used for various tests bearing on the question as to whether ions are produced when ozone is exposed to light of short wavelengths, the study of ionization of ozone being one line of attack on the problem of how the radio fade-outs which accompany solar eruptions are produced. The tests show that when a mercury-arc lamp is operated, a large number of large ions appear which, when the lamp is cut off, disappear only gradually over a period of several hours. The small ion-counter shows only a moderate increase in the number of small ions, although they must be produced in enormous quantities, since they can

only persist an extremely short time before becoming identified with large ions. Some of the tests showed that the large ions result from the action of the radiations from the lamp on some as yet undetermined material in or of the atmosphere and are not particles given off directly by the lamp itself. It was also found that small molecular ions, produced in considerable quantities by ionium, substituted for the arc-lamp and placed at the intake of the counters, did not grow in their progress through the apparatus nor did the intermediate-ion or large-ion content show any increase during periods when ionium was used as an ionizer. This investigation is still in progress.

Experiments were made to test more thoroughly the reliability and characteristics of apparatus used for the measurement of air-conductivity and the concentration of small ions. These verified previous conclusions, that the conductivity-apparatus, as generally used in the work of the Department, yields accurate results and that the values measured with the ion-counting apparatus require a correction when intermediate ions are present in sufficient concentration.

A study of the observations of nuclei made at 8^h daily at Huancayo provided a clue which, together with meteorological and other data, permitted the formulation of a satisfactory explanation of the remarkable contrast between day and night in air-conductivity and electric field-strength at Huancayo, especially during the dry season.

Measurements of air-conductivity in the free atmosphere up to an altitude of 22 km, when compared with cosmic radiation led to the conclusion that the coefficient of recombination between small ions varies directly as the pressure to the one-third power instead of the first power as usually assumed. Confidence in calculations of conductivity from cosmic-ray intensity was strengthened by investigations made at Loeb's laboratory of the University of California. It accordingly seemed worth while to make such calculations for different latitudes since the cosmic-ray intensity at the surface depends somewhat on latitude but more especially because the variation with altitude shows a pronounced dependence upon latitude. The calculations indicate that the conductivity at the surface over the oceans, where ions are produced almost exclusively by cosmic radiation, is on the average nearly independent of latitude, the higher temperatures at the low latitudes practically counteracting the smaller intensity of cosmic radiation there.

The interpretation of registrations of air-conductivity made on the flight of *Explorer II* also indicated that, although Aitken nuclei occur in negligible quantity in the altitude range 6 km to 18 km, yet from 19 km to 22 km they are present in sufficient abundance to reduce the air-conductivity to less than half the value which is to be expected in pure air at the highest altitude of the observations (22 km). This bank of nuclei apparently coincides in position with a corresponding bank of ozone. That this correspondence may be significant is indicated by the observations that Aitken nuclei are formed in great abundance by the ultraviolet light from a quartz-mercury vapor lamp.

Although it is now established that a decrease in the intensity of cosmic radiation sets in at some altitude (16 km near the equator and about 24 km at 51° north magnetic latitude), yet the conductivity cannot decrease with altitude at any altitude unless some factor other than the observed decrease in cosmic-ray intensity is involved. From this

and other considerations it now seems likely that there are factors, such as Aitken nuclei, which generally reduce the conductivity, in parts of the stratosphere, to values lower than those usually estimated.

Investigations of the electrode-effect in the atmosphere, the electric convection near the Earth's surface in fair weather, and world-wide variations in atmospheric electricity, have been made.

Geoelectricity—The investigation of the lunar diurnal variation in earth-currents was continued using the records from Tucson and Huancayo for the year 1932. The monthly mean lunar diurnal variation was found to be quite definitely semidiurnal in character and its amplitude was found to be less than one magnitude smaller than that of the solar diurnal variation. Harmonic analyses show that the amplitude of the predominant second harmonic is about one-sixth that of the solar diurnal variation at Huancayo and about one-fifth that of the solar diurnal variation at Tucson. The form of the mean curves is the same for both the equatorial station, Huancayo, and the middle-latitude station, Tucson. In this respect they differ markedly from the curves of solar diurnal variation.

The manner in which the lunar diurnal variation changes with the phase of the Moon was also examined. Both components at Huancayo show a marked increase in activity during daylight hours and a corresponding diminution during the night, so that the curves constructed for a given phase of the Moon are no longer of a simple semidiurnal character. These changes are similar to those found in the corresponding curves for the magnetic element. The Tucson data indicate that there is less difference between conditions during day and night affecting lunar diurnal variation at this middle-latitude station.

Ionospheric research—The productive field of investigation which was opened during the past two years with the discovery that magnetic effects of the diurnal-variation type are associated with certain bright chromospheric eruptions, and accompanying radio fade-outs in the sunlit hemisphere, was pursued vigorously during the past year. Understanding of the underlying nature of the regular daily changes of the Earth's magnetism which has come through this approach has proved most illuminating. The results represent a most important advance in the science of terrestrial magnetism in recent years. It is an interesting commentary that the broader inferences of these physical effects are becoming apparent through collaboration of workers in diverse fields of physics who observe them in their different aspects.

Isolation of the radio fade-out effect in a particular region of the ionosphere was accomplished using the powerful automatic multi-frequency technique. The ionization in the outer atmosphere produced by the ultraviolet light emanating from the bright chromospheric eruptions is absorbed almost exclusively below the level of about 90 km. This constitutes strong confirmatory evidence that the electrical currents causing the diurnal variation in the Earth's magnetism must flow below this level. That the ultraviolet radiation from the bright eruptions on the Sun is not absorbed in the higher regions of the outer atmosphere in passing through them is new evidence of the physical constitution of these regions, and of the processes producing ionization in them. This provides a new approach to the study of physical problems of the outer atmosphere and of the Sun.

Continual recording of the electrical state of the outer atmosphere is now an accomplished fact at the magnetic observatories of the Department at Huancayo and at Watheroo. Installation of the automatic multifrequency equipment represents the culmination of a long period of research and development by the Department to make possible a complete record of ionospheric fluctuations. Thus the ionosphere—the region of transition in which many solar effects are translated into observed geophysical phenomena—is now under continuous observation.

The experimental determination of the Lorentz polarization correction in the ionosphere represents a major contribution to the field of classical physics. The relation between the constitution of a conducting medium and its refractive index is a fundamental problem of physics to which attention has been devoted for many years. Heretofore, no experimental determination of this correction had been made, so that the experiments in the ionosphere represent the first factual evidence which has been brought to bear on the subject.

Nuclear physics—Studies in the laboratory of the primary particles of matter, which have magnetic properties as one of their very few attributes, were directed chiefly toward accurate measurements of the large attractive forces which operate inside the nuclei of all atoms. The Department's pioneer measurements two years ago on these nuclear forces, which are neither gravitational nor electromagnetic, but something "new," were amply confirmed here and elsewhere, and are accepted as fundamental to any understanding of the nature of matter and the primary physical forces. The observations of this year, made with a different apparatus and completely independent of the earlier series, served to calibrate all the measurements on an absolute scale (centimeters, grams, seconds) as required for theoretical interpretation and universal applicability.

The construction of a high-voltage equipment for nuclear physics, having adequate range and characteristics for a comprehensive program of precision measurements, was the chief feature of the work during the year. This Atomic-Physics Observatory (see Plate I) comprises a constant-potential (electrostatic) generator and vacuum-tube designed to reach potentials in excess of five million volts under precise control. Insulation is by dry air compressed to 50 pounds per square inch in a pear-shaped steel tank 55 feet high and 37.5 feet in diameter. Adequate provision is made for shielding observers and instruments (against penetrating radiations) and for auxiliary equipment.

Magnetic survey—Collection, compilation, and discussion of data pertaining to the world magnetic survey were continued. Owing to the limited funds available for the survey only a modest amount of field-work could be undertaken.

The principal work was done in Asia, where six stations were occupied in Malaya, five stations in Siam, and five stations in Indo-China. In addition, continuing the extensive program of field-work in Australia and the Pacific islands, inaugurated in 1936, magnetic observations were made in Suva, Fiji, and Blacktown near Sydney, prior to an expedition into the Pacific during which stations were occupied in New Hebrides (3), in Tahiti (4), and in New Caledonia (2). Comparisons of instruments were secured at Batavia, Blacktown, Honolulu, and Watheroo. Repeat-stations at two points in Western Australia were occupied.

Six stations were also occupied in the Northern Territory of Australia, by the Aerial, Geological, and Geophysical Survey of Northern Australia, in cooperation with the Department.

Maintenance of International Magnetic Standards of the Department was continued in cooperation with the United States Coast and Geodetic Survey at the Cheltenham Magnetic Observatory.

Observatory-work—At the Watheroo and Huancayo magnetic observatories continuous records were obtained of the three magnetic elements, of atmospheric potential-gradient, of positive and negative conductivity of the atmosphere, of earth-currents, of ionospheric phenomena, and of the meteorological elements. Until November 1937 at Huancayo, and May 1938 at Watheroo, the ionospheric records were obtained with a fixed-frequency apparatus with manual-controlled multifrequency observations twice a week; thereafter they were obtained with the automatic multifrequency equipment, developed in the Department, capable of continuous operation. In the short time that the multifrequency equipment has been in operation a large number of valuable data have been accumulated.

Daily observations, weather permitting, were made with the Hale spectrohelioscope at stated times so as to tie in with the solar-disturbance program of the International Astronomical Union for world-wide continuous observations of the Sun. Huancayo in addition obtained continuous records with a three-component seismograph and with a Compton precision cosmic-ray meter.

Cooperative work was continued with the MacGregor Arctic Expedition which maintained a magnetic observatory near Reindeer Point, Etah, Greenland, using materials and apparatus supplied by the Department. The cooperative program in atmospheric electricity and earth-currents was continued at Tucson, Arizona, with the assistance of the United States Coast and Geodetic Survey and Bell Telephone Laboratories. The cooperative work in atmospheric electricity was continued with the Apia Observatory of the Department of Scientific and Industrial Research of New Zealand. The Department supplied forms for observatory- and field-work to the magnetic observatory at Capetown, South Africa. Cheltenham Magnetic Observatory operated the CIW vertical-intensity inductometer during the year and utilized the Department's standard instruments—CIW sine-galvanometer and Schulze earth-inductor for standardizations in horizontal intensity and inclination, respectively.

Oceanographic reductions—Final revision of manuscript and discussion of the meteorolgical results obtained during the seventh cruise of the *Carnegie* was completed. The title of the manuscript is "Meteorological results of Cruise VII of the *Carnegie*, 1928-1929," by K. B. Clarke-Hafstad and W. C. Jacobs. It is planned to publish it as part of volume IV of the series "Results of oceanographic and meteorological work obtained on board the *Carnegie*, Cruise VII, 1928-1929, under the command of J. P. Ault."

Miscellaneous work—The cooperation with other investigators and organizations engaged in work similar to that of the Department has been continued as in the past.

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CORRELATION OF MAGNETIC ACTIVITY WITH DISTURBANCE OF RADIO TRANSMISSION

By A. G. McNish and H. F. Johnston

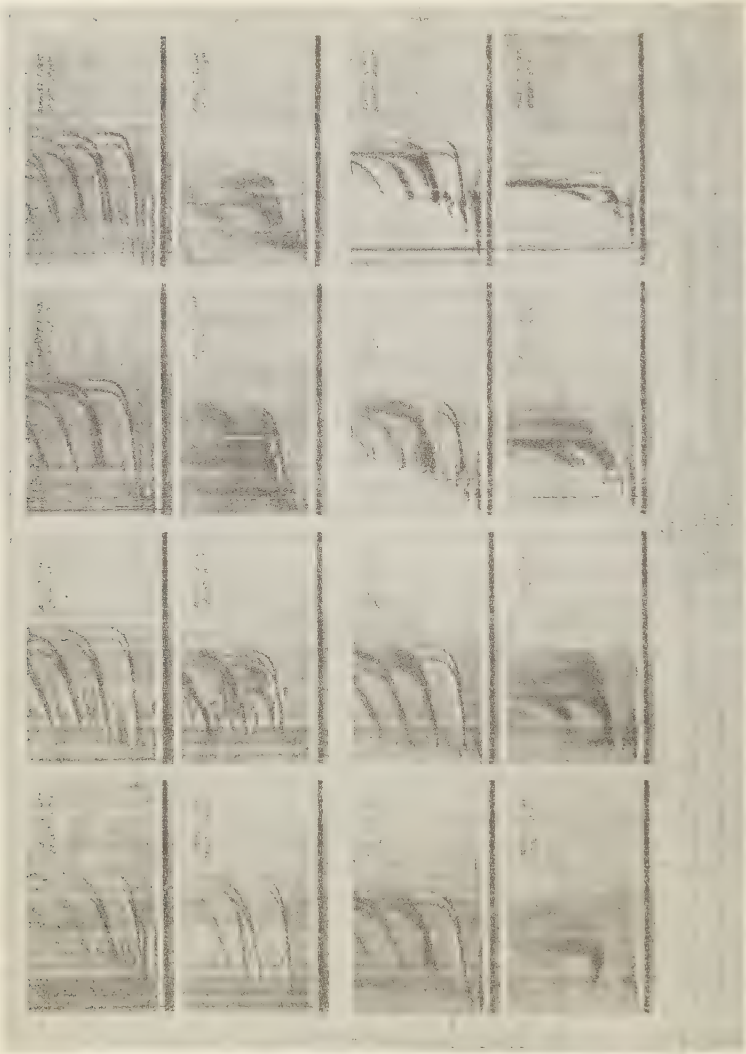
Owing to their mutual dependence on conditions in the ionosphere a close connection between magnetic activity and radio transmission is expected. This connection is revealed by impairment of transmission on high frequencies during magnetic storms, ranging from complete failure of certain channels of communication during severe magnetic storms to minor vitiation during periods of lesser activity.

The first experimental evidence on the nature of the changes taking place in the reflecting properties of the ionosphere during a magnetic storm were supplied by Hafstad and Tuve (see 1 under "References" at end of this article) in 1929. Limitations in technique at that time prevented comprehensive observation of the changes taking place. Subsequent developments in methods of ionospheric research at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington and elsewhere, particularly the introduction of automatic multifrequency methods [2, 3] have afforded a clearer understanding of the phenomena.

Behavior of the ionosphere in middle latitudes during times of moderate magnetic activity have been described by Berkner [4]. At such times irregular scattered reflections are frequently obtained from the *F*-region at vertical incidence (see Figure 1, taken from the abovementioned paper) and depression of the *F*-region critical frequency often occurs.

Close to the auroral zone where the effects of magnetic storms are most strongly manifested the concomitant effects on radio transmission are also most pronounced. Harang [5] has reported frequent cessation of reflection from the higher region of the ionosphere during magnetic disturbance. During more intense magnetic disturbances cessation of reflection from the higher region extends to low latitudes, even to the geomagnetic equator. The National Bureau of Standards has reported [6] that no reflections could be obtained from the upper region of the ionosphere at Washington, D. C., during certain parts of the intense magnetic storms on January 22, 1938 and April 16, 1938. Ionospheric records obtained with the new multifrequency equipment at the Huancayo Magnetic Observatory of the Department of Terrestrial Magnetism also reveal cessation of reflections from the upper regions at these times. Huancayo is located 0°.6 south of the geomagnetic equator and 12°.0 south of the geographic equator. Fade-outs of this type are quite distinct from the fade-outs caused by bright eruptions in the solar chromosphere; the former may occur during hours of darkness and are most pronounced in high latitudes while the latter are confined to the daylight portion of the Earth and are most pronounced in low latitudes.

A number of investigators have suggested that the fade-outs occurring during magnetic storms are due to an absorbing layer produced at low levels, similar in some features to the absorbing layer produced by ultra-



violet light from chromospheric eruptions. Records from Huancayo support this view. Cessation of upper-region reflections during the storm of January 22 was accompanied by reflections from about the E-level extending over the entire frequency-range within which upper-layer reflections are ordinarily obtained, resembling sporadic E-layer reflections. These effects occurred during the night-hours when commercial high-frequency radio circuits between North America and South America and between North America and Europe were blanketed.

The fade-out during the storm of April 16 was not accompanied by low-layer reflections over such an extensive frequency-range, although during part of the fade-out low-layer reflections were obtained over a restricted portion of the frequency-range. After the fade-out extraordinarily great minimum virtual heights for the *F*-region were recorded, suggestive of abnormal retardations at lower levels. This fade-out, like the one on January 22, also occurred during the night-hours when high-frequency communication channels were destroyed.

Existence of a similar but less efficient absorbing layer formed during moderate magnetic storms seems a reasonable explanation for much of the impairment of transmission at those times. Such a layer might escape detection by observations involving reflection at vertical incidence and yet contribute strongly to absorption of waves reflected at oblique incidence which must traverse greater distances in the absorbing region. A more pronounced effect of this layer in higher latitudes is supported by the facts that cessation of reflections from the upper regions is more common near the auroral zone and that the durations of the fade-outs on January 22 and on April 16 were much greater at Washington than at Huancayo. The experimental facts explain the observation that radio circuits traversing high-latitude paths are more subject to impairment during magnetic storms than those traversing low-latitude paths.

Success of attempts to derive numerical relations between disturbance of radio transmission and magnetic activity depend upon selection of appropriate measures of the two variables. A new measure of magnetic activity, the American magnetic character-figure (C_A), was introduced early in 1937 for application to the study of such problems. This new measure is based on reports from the seven magnetic observatories operated by American organizations, namely, those of the Department of Terrestrial Magnetism at Huancayo, Peru, and at Watheroo, Western Australia, and those of the Coast and Geodetic Survey at Cheltenham, Maryland, at Honolulu, Hawaii, at San Juan, Puerto Rico, at Sitka, Alaska, and at Tucson, Arizona. Each observatory assigns a character-figure, descriptive of the intensity of magnetic disturbance, to each Greenwich half-day running from 0^h to 12^h and from 12^h to 24^h Greenwich mean time. These character-figures range by steps of 0.5 from 0.0 to 2.0, 0.0 signifying little or no magnetic disturbance and 2.0 signifying the most intense degree of magnetic disturbance. The average of these values constitutes the American magnetic character-figure. Fuller descriptions of this measure and its significance have been published previously [7, 8].

As a measure of radio disturbance the transmission-disturbance figure for the high-frequency circuits between New York and London was selected. These figures are daily index-numbers proportional to the depression of the average field-strength of the signal below the normal value in decibels, the normal value being determined by the average of the ten preceding days having a transmission-disturbance figure of 1.5 or less. Effects of seasonal and year-to-year variations in conditions and frequencies of transmission are largely eliminated by referring these figures to a normal value. On the basis of the hypothesis of an absorbing layer the depression of field-strength below normal is an appropriate measure of radio disturbance.

For the interval from December 18, 1937 to May 18, 1938 the correlation-coefficient of the two measures was 0.73. The relation between the two variables is essentially linear (see Fig. 2), which demonstrates the suitability of choice of measures. Attempts to correlate the inter-

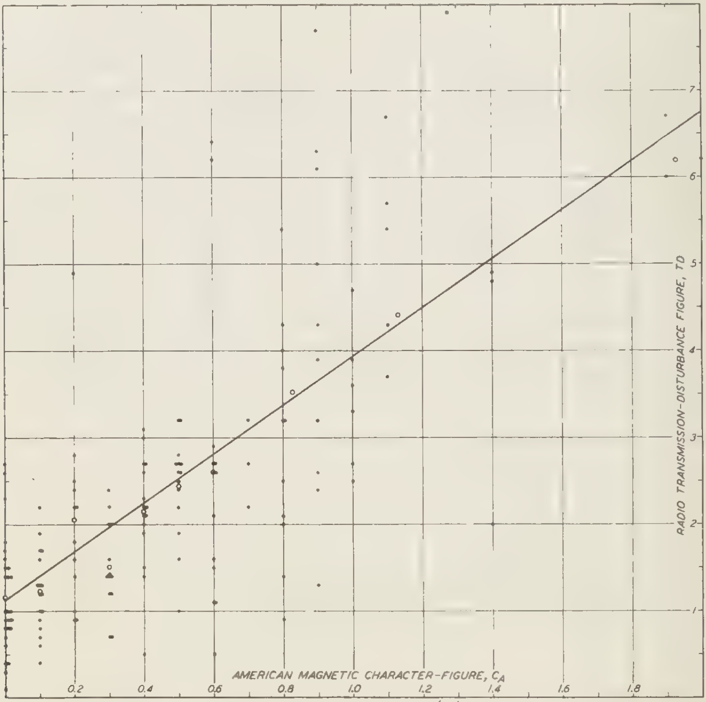


FIG. 2—RELATION RADIO TRANSMISSION-DISTURBANCE FIGURE (TD) OVER NORTH ATLANTIC AND AMERICAN MAGNETIC CHARACTER-FIGURE (C_A), INDIVIDUAL DAYS, DECEMBER 18, 1937 TO MAY 18, 1938
$TD = 1.1 + 2.86\ C_A$ —CORRELATION-COEFFICIENT $(r) = 0.73$

national magnetic character-figure with the transmission-disturbance figure would lead to a lower coefficient because of the absence of this linear relation; the international figure does not furnish much discrimination between highly disturbed days when radio transmission is most affected but does furnish such discrimination among slightly disturbed days when radio transmission is not noticeably affected.

A correlation-coefficient of 0.70 was obtained for a lengthier period extending from January 1, 1937 to April 30, 1938 (see Fig. 3). Based on over 480 pairs of values this coefficient must be regarded as highly significant. This coefficient may be interpreted as indicating that the two variables have 70 per cent of their origin in a common cause. However, the relation is not extremely valuable for prognostic purposes; the error in estimating the transmission-disturbance figure from the American magnetic character-figure is still 0.71 as great as if the latter were not known. Several significant features stand out when the two

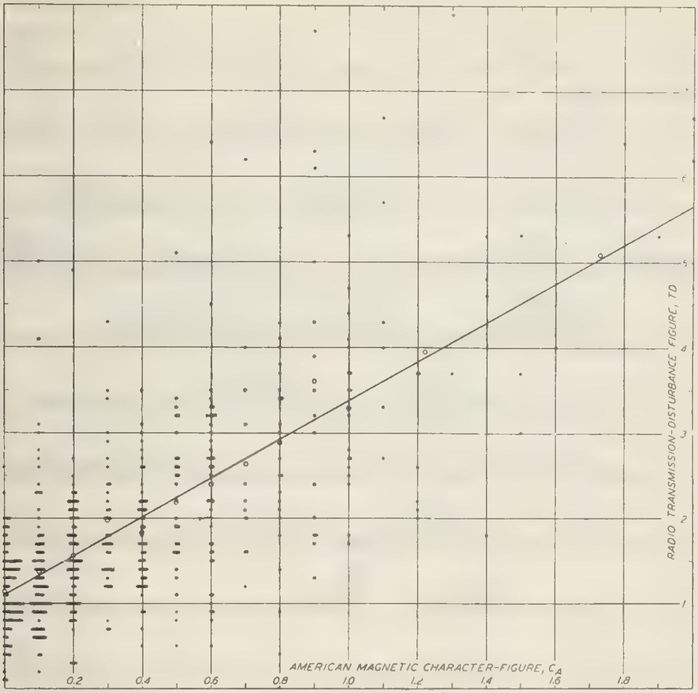


FIG. 3—RELATION RADIO TRANSMISSION-DISTURBANCE FIGURE (TD) OVER NORTH ATLANTIC AND AMERICAN MAGNETIC CHARACTER-FIGURE (C_A), INDIVIDUAL DAYS, JANUARY 1, 1937 TO APRIL 30, 1938
$TD = 1.1 + 2.28\, C_A$ — CORRELATION-COEFFICIENT $(r) = 0.70$

variables are plotted. Of the 11 days in the interval having magnetic character-figures greater than 1.3 only two had transmission-disturbance figures less than four, which corresponds to a depression of field-strength of the received signal by 21 decibels, or over 100-fold, while of the 215 days having magnetic character-figures less than 0.3 only five experienced so great a depression of signal-strength.

However, the closeness of this relationship justifies the conclusion that disturbances in radio transmission, like magnetic activity, depend on solar conditions. Much independent evidence on this matter has been accumulated but the radio observations do not extend over a sufficiently long period to regard the evidence as statistically conclusive. Since the solar-magnetic relationship has been definitely established by statistical means its implications may now be applied to radio phenomena.

A tendency for magnetic disturbance to recur at 27-day intervals has been adequately established. During the last few years when radio data have been most complete this 27-day recurrence tendency has not been pronounced, so that lack of strong evidence for it has led investigators to doubt its validity in radio phenomena. Comparison of daily values of the magnetic character-figure with the daily values of the transmission-disturbance figure plotted in 27-day sequences (see Figs.

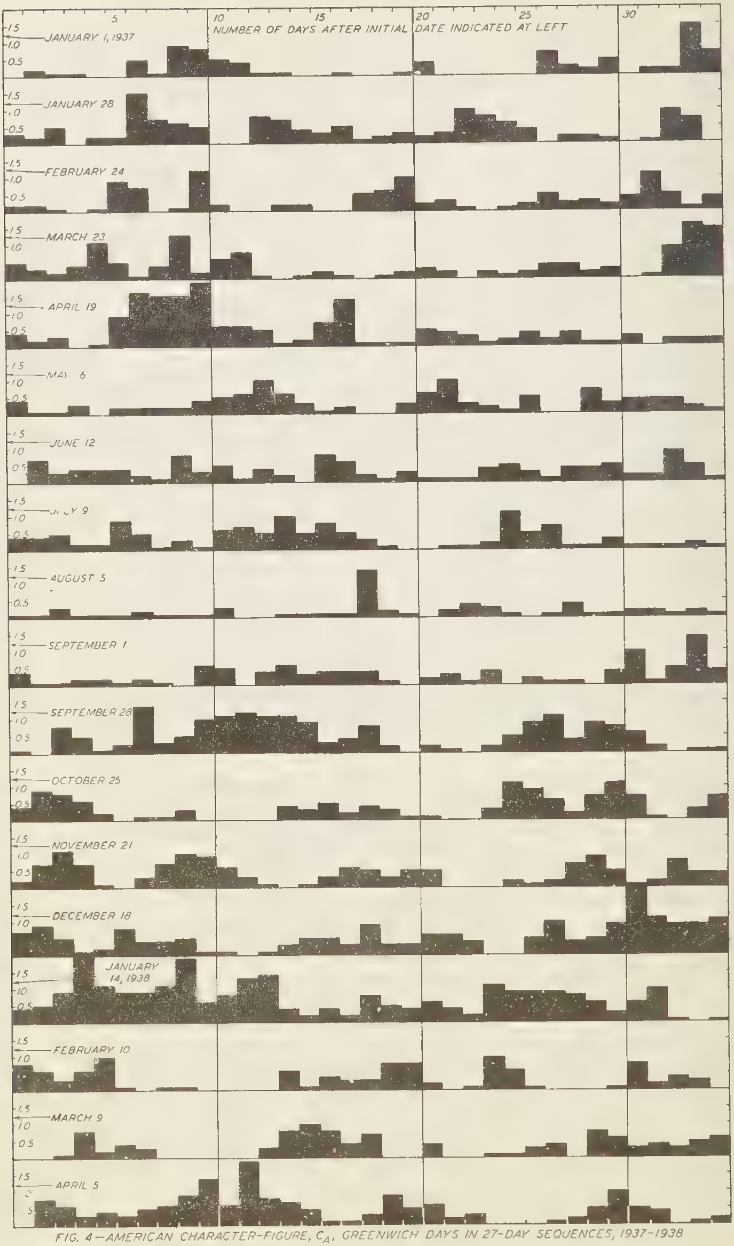


FIG. 4—AMERICAN CHARACTER-FIGURE, C_A, GREENWICH DAYS IN 27-DAY SEQUENCES, 1937–1938

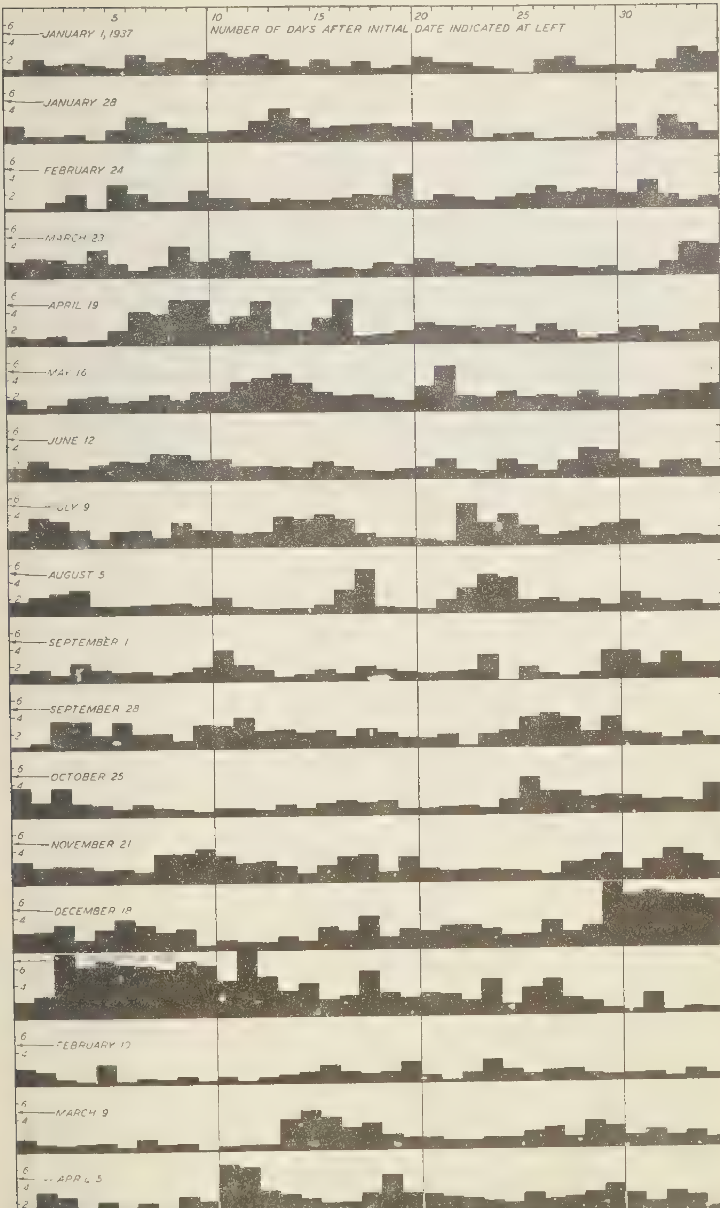


FIG. 5—RADIO TRANSMISSION-DISTURBANCE FIGURE, TD, OVER NORTH ATLANTIC, GREENWICH DAYS IN 27-DAY SEQUENCES, 1937 1938

4 and 5) indicates that the same patterns appear in both. Reality of the 27-day recurrence of magnetic disturbances could not have been established by the data from January 1, 1937 to May 10, 1938. A large number of violent magnetic storms, which do not appear to conform to the recurrence-principle, occurred during the interval in question. It may be expected that when the present interval of excessive activity has been passed the tendency for 27-day recurrence will again be marked in the magnetic data and hence will also be revealed in the behavior of radio transmission-conditions.

Another measure of magnetic activity, the Potsdam magnetic index, has recently been introduced by Bartels [9]. The index consists of two numbers, the first of which indicates the intensity of magnetic activity and the second designates the character of activity in accordance with an established code. Pairs of index-numbers are given for each three-hour interval in the Greenwich day. The first index-number is determined by the departure of the range in one of the elements, declination, horizontal intensity, or vertical intensity, whichever shows the greatest departure, from the average range for that interval determined by the quiet-day variations. The ranges are reduced by a logarithmic scale to give the index-number in order that a suitable scale of activity may be

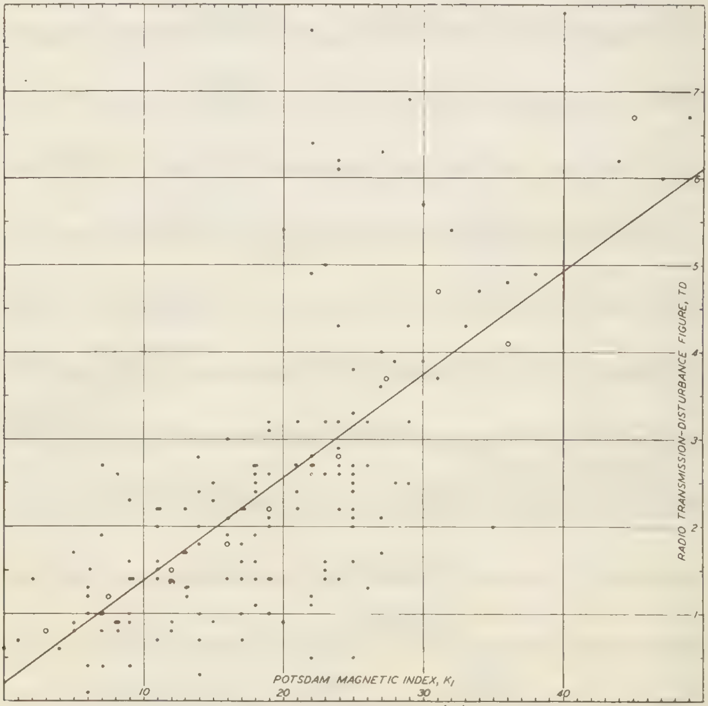


FIG. 6—RELATION RADIO TRANSMISSION-DISTURBANCE FIGURE (TD) OVER NORTH ATLANTIC AND POTSDAM MAGNETIC INDEX (K_I), INDIVIDUAL DAYS, DECEMBER 18, 1937 TO MAY 18, 1938
$TD=0.2+0.12\ K_I$ —CORRELATION-COEFFICIENT $(r)=0.67$

obtained; thus there are seven index-numbers corresponding to ranges less than 200 gammas and only three index-numbers corresponding to greater ranges. The sum of the first figures for the eight intervals supplies an index-number for the entire day

The correlation-coefficient relating the Potsdam magnetic index with the transmission-disturbance figure for the period December 18, 1937 to May 18, 1938, was 0.67, as compared with 0.73 when the American magnetic character-figure was employed for the same interval. The relationship between the Potsdam magnetic index and the transmission-disturbance figure is linear (see Fig. 6). This difference in correlation-coefficients is probably statistically significant, being based on 152 pairs of values but it does not indicate any marked superiority of one measure over the other for this purpose. It is unlikely that geographical distribution of the stations contributing to the American magnetic character-figure is responsible for the difference since Potsdam is about as close to the transmission-path across the North Atlantic as most of the American stations.

A very high correlation, 0.94, was obtained between the American magnetic character-figure and the Potsdam magnetic index. The relationship between the two measures is linear throughout most of the range (see Fig. 7), a departure from linearity occurring only for low

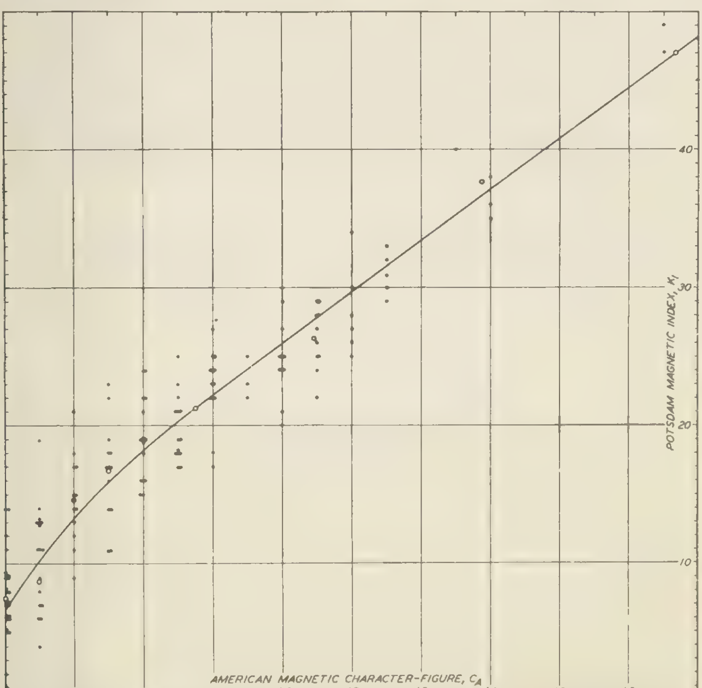


FIG 7—RELATION POTSDAM MAGNETIC INDEX (K_I) AND AMERICAN MAGNETIC CHARACTER-FIGURE (C_A), INDIVIDUAL DAYS, DECEMBER 18, 1937 TO MAY 18, 1938—CORRELATION-COEFFICIENT (r)=0.94

degrees of activity. This high correlation is quite striking in view of the complete independence of the two measures and the difference in the methods by which they are obtained. The highest correlation between the American magnetic character-figure and the stations contributing to it for a three-month interval was 0.93, but in obtaining this correlation the half-day interval was used; the results should be improved by inclusion of whole-day intervals. The Potsdam magnetic index has the advantage, in spite of the additional amount of labor in determining it, that it is entirely objective. However, the high correlation-coefficients which have been obtained attest strongly to the reliability of purely subjective methods of assigning magnetic character-figures, particularly when care and judgment are used in making the estimates.

The writers are indebted to the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, and the United States Coast and Geodetic Survey for the data upon which the American magnetic character-figure are based. The data on radio transmission were supplied through the courtesy of Dr. A. L. Durkee of the Bell Telephone Laboratories. Values of the Potsdam magnetic index were taken from an article by J. Bartels in the place cited.

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AN IONOSPHERIC INVESTIGATION CONCERNING THE LORENTZ POLARIZATION-CORRECTION

By H. G. Booker and L. V. Berkner

Abstract—Some years ago considerable discussion took place concerning the relation between the constitution of the ionosphere and its refractive index for radio waves. The question at issue was whether the force per unit-charge exerted by the electric field of a radio wave upon an elementary charged particle in the ionosphere should be taken simply as the Maxwellian electric intensity **E** (the Sellmeyer theory), or whether there should be added a contribution $(4\pi/3)\mathbf{P}$ (the Lorentz theory). The discussion culminated in a theoretical treatment of the subject by Darwin which seemed to point to the conclusion that the Sellmeyer theory should hold good in the ionosphere at radio frequencies.

For reflection from the ionosphere of radio waves of frequency less than the gyromagnetic frequency there is in middle latitudes a clear-cut distinction in the behavior of the extraordinary wave according to the two theories. Over the past year a large number of records showing magneto-ionic splitting of ionospheric echoes at these wave-frequencies have been obtained. We are led to believe that it is impossible to interpret these observations in terms of the Sellmeyer theory but that no objection exists to their interpretation in terms of the Lorentz theory.

On the basis of the Lorentz theory the observations indicate that there is in the *E*-region of the ionosphere a level of maximum atomic and molecular ion-density somewhat below the level of maximum electron-density.

1—*Introduction*

The relation between the refractive index and the constitution of a conducting medium is a fundamental problem of classical physics to which attention has been devoted for many years but which even now is not completely solved. The force per unit-charge exerted by an electric field upon an elementary charged particle in the medium is of the form

$$\mathbf{E}+4\pi l\mathbf{P} \tag{1}$$

where **E** is the Maxwellian electric intensity and **P** is the electric moment per unit-volume produced by the electric field in the neighborhood of the charged particle under consideration. The question at issue is whether

$$l=0 \text{ (the Sellmeyer theory)} \tag{2}$$

or

$$l=1/3 \text{ (the Lorentz theory)} \tag{3}$$

For conduction-electrons in metals under the influence of the steady and alternating electric fields ordinarily encountered in electrical engineering the validity of the Sellmeyer theory is universally taken for granted. The Lorentz theory would be inconsistent with Ohm's Law and would in fact render the medium electrically unstable. It may therefore be regarded as beyond question that, for a medium whose electrical properties are determined primarily by the free charges it contains, it is the Sellmeyer theory which must be used at sufficiently small oscillation-frequencies. For a long time it was supposed that the oscillation-frequency could be increased indefinitely without in any way affecting the validity of the Sellmeyer theory. This view was supported by the fact that, even at the frequencies of visible light, only the Sellmeyer theory could satisfactorily explain the behavior of metallic con-

ductors. However, for a rarefied gas rendered conducting by ionizing radiation, no information was available concerning the extent to which the oscillation-frequency could be raised without affecting the validity of the Sellmeyer theory. When the discovery of reflection of radio waves from the ionosphere aroused particular interest in the electrical properties of an ionized medium, it was at first assumed that for such a medium the oscillation-frequency could be raised to the values used in radio communication without affecting the validity of the Sellmeyer theory. This view was challenged in 1929 by Hartree [see 1 under "References" at end of paper] who expressed the opinion that it is the Lorentz theory which should be used in the ionosphere at radio frequencies. There followed considerable discussion which culminated in 1934 in a theoretical treatment of the subject by Darwin [2]. Darwin's work is the most exhaustive discussion of the question so far published and seemed to point to the conclusion that on theoretical grounds one should expect the Sellmeyer theory to hold good in the ionosphere at radio frequencies.

A need exists for experimental investigation of the electrical properties of a rarefied gas rendered conducting by ionizing radiation. The difficulty of performing such an investigation within the confined space of a laboratory is obvious, and the most promising line of approach would seem to be direct radio sounding of the ionosphere itself. Two important experimental methods for deciding between the Sellmeyer and Lorentz theories by radio sounding of the ionosphere have been proposed and tried.

One method, due to Farmer and Ratcliffe [3], is based upon the fact that the dependence of skip-distance upon wave-frequency is different for the two theories. Experiments using this method have been made by Farmer, Childs, and Cowie [4]. They find that their observations are in approximate agreement with the Sellmeyer theory provided the influence of the Earth's magnetic field is neglected. Unfortunately it is difficult, under the conditions of the experiments, to calculate with the necessary precision either the effect of the Earth's magnetic field or the magnitude of the discrimination between the two theories. Both these factors appear to be of an order of magnitude similar to the experimental uncertainty. Because of the difficulty of interpreting the observations, this method has not yet yielded a decisive result.

The second method of deciding between the Sellmeyer and Lorentz theories was originally indicated by Ratcliffe [5] and subsequently described in greater detail by Goubau [6, 7]. It involves the fact that, for radio waves, the ionosphere is rendered doubly-refracting by the influence of the Earth's magnetic field. Free electrons in the ionosphere gyrate around the Earth's magnetic field with a frequency of the order of a megacycle per second. For wave-frequencies less than the gyromagnetic frequency there is, under suitable conditions, a clear-cut distinction in the behavior of the extraordinary wave according to the two theories. Experimental observations bearing upon this second method have been obtained over the past year at the experimental station maintained at Kensington, Maryland, U.S.A., by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. Comparison with Goubau's theoretical treatment leads us to believe that our observations cannot be interpreted in terms of the Sellmeyer theory.

Section 2 of this paper is a review of Goubau's method for deciding between the two theories. Our experimental observations bearing upon

this method are described in Section 3, and their interpretation is discussed in Section 4. We first attempt and fail to interpret the observations in terms of the Sellmeyer theory, and subsequently succeed in interpreting them in terms of the Lorentz theory. This interpretation seems to point to some interesting possibilities concerning the nocturnal distribution of ionization with height in the E-region of the ionosphere. Section 5 is a review of the theoretical aspect of the problem of discriminating between the Sellmeyer and Lorentz theories.

2—*A critical discrimination between the Sellmeyer and Lorentz theories*

The ionosphere may be thought of ideally as an ionized medium in which the density N of free electrons is zero up to a certain height above the surface of the Earth and then increases linearly with height as shown

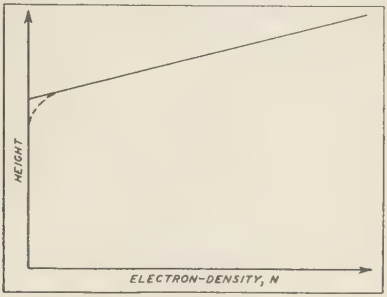


FIG. 1—IDEAL IONOSPHERE

in Figure 1. Suppose that a wave-packet is incident vertically upon such an ionosphere. It sets the electrons in vibration and as a result is slowed down. It is ultimately brought instantaneously to rest and then retraces its path back to the surface of the Earth. One-half of the time of flight of the wave-packet multiplied by the velocity of light *in vacuo* is called the virtual height of reflection of the wave-packet. Owing to the influence of the Earth's magnetic field the ionosphere is a doubly-refracting medium. Consequently a wave-packet of arbitrary elliptical polarization is split on entering the ionosphere into two characteristically polarized wave-packets—the ordinary and extraordinary magneto-ionic components. These two characteristically polarized wave-packets do not in general follow the same path. For a vertically incident wave-packet the two magneto-ionic components do not in general continue in a vertical straight line. The paths which they follow on the upward journey in the ionosphere, and which they retrace on the downward journey, are in general non-coincident plane curves lying in the magnetic meridian. The virtual heights of reflection of the two magneto-ionic components are different, and both depend upon the oscillation-frequency of the incident wave-packet.

For a wave-packet incident vertically upon an ionosphere in which the electron-density increases linearly with height as shown in Figure 1, Goubau [6, 7] has calculated the way in which the virtual height of reflection varies with the wave-frequency. Figure 2 shows the type of dependence of virtual height upon wave-frequency obtained for the

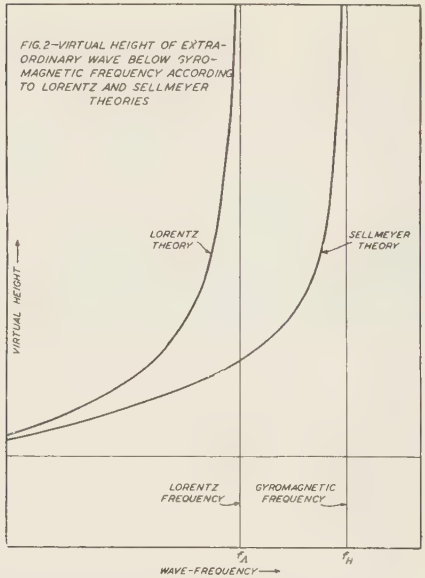


FIG. 2—VIRTUAL HEIGHT OF EXTRAORDINARY WAVE BELOW GYROMAGNETIC FREQUENCY ACCORDING TO LORENTZ AND SELLMEYER THEORIES

extraordinary wave at wave-frequencies less than the gyromagnetic frequency. For the Sellmeyer theory the virtual height increases to infinity as the wave-frequency f increases to the gyromagnetic frequency f_H. The same is true for the Lorentz theory provided the magnitude of the magnetic dip I is less than or equal to $\sin^{-1}(1/\sqrt{3})$, which is about 35°. If, however, $|I| > \sin^{-1}(1/\sqrt{3})$, then the virtual height according to the Lorentz theory increases to infinity as f increases to a fre-

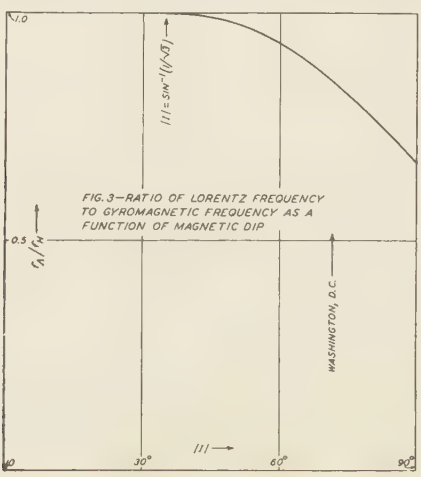


FIG. 3—RATIO OF LORENTZ FREQUENCY TO GYROMAGNETIC FREQUENCY AS A FUNCTION OF MAGNETIC DIP

quency which we shall call the Lorentz frequency and which is denoted in Figure 2 by f_Λ. Figure 3 shows the way in which the ratio of the Lorentz frequency to the gyromagnetic frequency depends upon magnetic dip. At Washington, D. C., where the magnetic dip is between 71° and 72°

$$f_\Lambda/f_H = 0{\cdot}85 \tag{4}$$

Consequently, if the increase of virtual height of the extraordinary wave to infinity indicated in Figure 2 can be observed, there should be no difficulty in deciding between the Sellmeyer and Lorentz theories.

It should be realized that the infinite virtual heights depicted in Figure 2 have no connection whatever with the infinite virtual height which occurs at the critical penetration-frequency of an ionospheric region. Figure 2 is drawn for a distribution of electron-density which increases linearly with height and has no maximum. The infinite virtual heights of Figure 2 in no way depend upon whether there is a level at which the electron-density is a maximum. Nor do they occur due to abnormal slowing down of the wave-packet near the level of reflection. It should also be realized that the cause of the infinite virtual heights shown in Figure 2 is quite different for the two theories. Moreover, different values of electron-density are responsible in the two cases.

In discussing the values of electron-density N responsible for the large virtual heights of Figure 2 it is convenient to compare them to a standard value N_0. We shall take N_0 to be the electron-density which would be required to reflect a vertically incident wave of the same frequency in the absence of the Earth's magnetic field. This is also the electron-density required to reflect the ordinary wave in the presence of the Earth's magnetic field. In the Sellmeyer theory the large virtual height occurring at wave-frequencies a little less than the gyromagnetic frequency is due to abnormal slowing down of the extraordinary wave-packet in the region where N is small compared to N_0. As soon as the extraordinary wave-packet is split off from the incident wave-packet it is slowed down almost to rest, and it is the slow rate of travel through the region of small electron-density which causes the large virtual height.

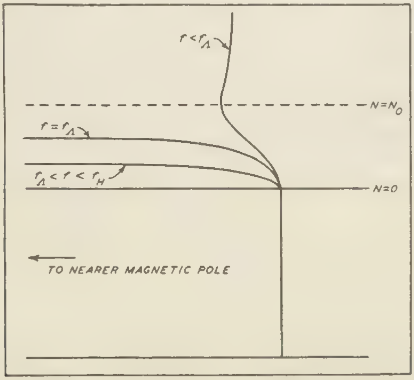


FIG. 4—LATERAL DEVIATION OF EXTRAORDINARY WAVE-PACKET BELOW GYROMAGNETIC FREQUENCY ACCORDING TO LORENTZ THEORY

On the other hand, for the Lorentz theory the large virtual height occurring at wave-frequencies a little less than the Lorentz frequency is due to large lateral deviation of the extraordinary wave-packet. For $f < f_\Lambda$ the wave-packet is deviated in the magnetic meridian as in Figure 4. As f increases towards f_Λ the magnitude of the lateral deviation towards the nearer magnetic pole increases. At $f = f_\Lambda$ there is a value of electron-density for which the lateral deviation actually becomes infinite. It remains infinite for $f_\Lambda \leq f < f_H$, and it is for this reason that no extraordinary reflected wave is to be expected for wave-frequencies between the Lorentz and gyromagnetic frequencies. The value of electron-density for which the lateral deviation becomes infinite at the Lorentz frequency depends upon the magnetic dip in the manner shown in Figure 5. For Washington, D. C., this value of electron-density is about

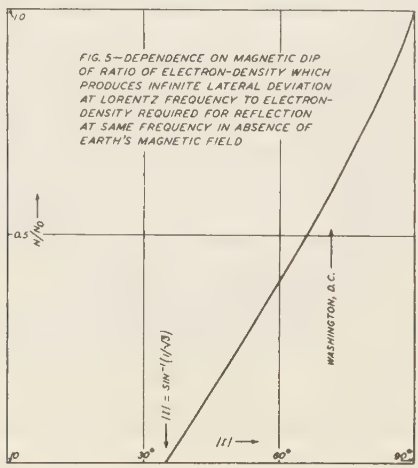


FIG. 5—DEPENDENCE ON MAGNETIC DIP OF RATIO OF ELECTRON-DENSITY WHICH PRODUCES INFINITE LATERAL DEVIATION AT LORENTZ FREQUENCY TO ELECTRON-DENSITY REQUIRED FOR REFLECTION AT SAME FREQUENCY IN ABSENCE OF EARTH'S MAGNETIC FIELD

$0.6\ N_0$. In this case, therefore, the electron-densities responsible for the large virtual height of the extraordinary wave just below the Lorentz frequency according to the Lorentz theory are considerably larger than those responsible for the large virtual height just below the gyromagnetic frequency according to the Sellmeyer theory.

The values of electron-density which are responsible for the large virtual height of the extraordinary wave also produce considerable absorption of the wave. In other words, the retarding stratum is also an absorbing stratum. In a preliminary communication [8] it was stated that at Washington, D. C., the reflection-coefficient just below the gyromagnetic frequency according to the Sellmeyer theory is considerably less than it is just below the Lorentz frequency according to the Lorentz theory. This statement was based upon Figure 9 of a paper by Goubau [6]. Unfortunately the ordinates in that Figure are an order of magnitude less than they should be, and to this extent the statement in the preliminary communication is wrong. For the same value of collisional frequency the absorption-coefficients in the respective ab-

sorbing strata have the same order of magnitude for the two theories. However, the absorbing stratum for the Sellmeyer theory occurs for considerably smaller values of electron-density than for the Lorentz theory. Hence the value of collisional frequency appropriate to the Sellmeyer theory may be significantly larger than that appropriate to the Lorentz theory. Moreover, the small values of electron-density, which are responsible for absorption in the case of the Sellmeyer theory, are liable to be spread out over a relatively large range of height as shown by the broken curve in Figure 1. The absorbing stratum may therefore be thicker for the Sellmeyer theory than for the Lorentz theory. In all probability it is still true that there is significantly greater chance in practice of recording the large virtual height of Figure 2 if the Lorentz theory is true than if the Sellmeyer theory is true. The actual reflection-coefficient for a wave-frequency about five per cent less than the Lorentz frequency according to the Lorentz theory may be estimated from Goubau's Figure 9 using the corrected ordinates. A mean value for the absorption-coefficient in the absorbing stratum is

$$\kappa = 2.5 \times 10^{-10} \cdot \nu \qquad (5)$$

where ν is the collisional frequency. Hence, if the absorbing stratum has a vertical thickness d km, it contributes a factor

$$\rho = \exp\left(-5 \times 10^{-5} \cdot \nu d\right) \qquad (6)$$

to the amplitude reflection-coefficient.

The two magneto-ionic components of a vertically incident wave-packet do not in general travel vertically in the ionosphere. But individual wave-crests within a characteristically polarized wave-packet do continue to move across the wave-packet vertically. The velocity of individual wave-crests is different from the velocity of the wave-packet as a whole. Its variation is conveniently represented by plotting the refractive index μ as a function of the electron-density N. For the extraordinary wave at wave-frequencies less than the gyromagnetic frequency, the Lorentz theory (omitting damping) gives curves of the type shown in Figure 6 [compare Taylor 9]. For $f_H > f > f_\Lambda$ there are two values of N for which $\mu = \infty$. The smaller of these is the electron-density for which the lateral deviation becomes infinite in Figure 4. As the wave-frequency decreases through the Lorentz frequency f_Λ, the two values of N for which $\mu = \infty$ pass from real to conjugate complex quantities via equality. This provides a simple means of calculating the value of the Lorentz frequency. We merely have to write down the equation giving the values of N for which $\mu = \infty$, and express the condition that it should have a pair of equal roots. This equation has been given by Taylor [9] and is

$$a \equiv (1+lx)\{(1+lx)^2 - y^2\} - x\{(1+lx)^2 - y^2 \sin^2 I\} = 0 \qquad (7)$$

where

$$x = \frac{1}{1-l}\,\frac{N}{N_0} \qquad (8)$$

$$y = f_H/f \qquad (9)$$

I is the magnetic dip and l is given by (3). The condition that the cubic (7) for x should have a pair of equal roots is

$$ay^4 + by^2 + c = 0 \qquad (10)$$

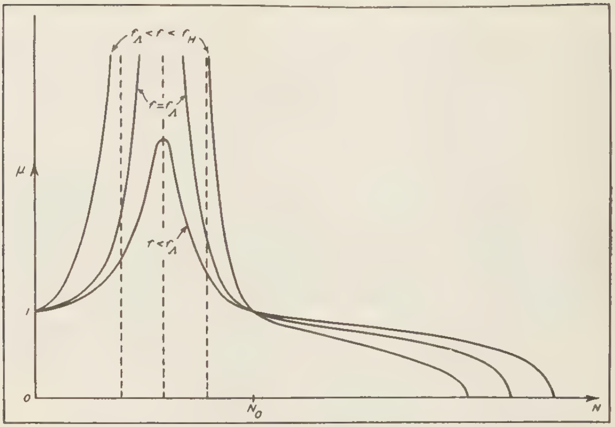


FIG. 6—REFRACTIVE INDEX AS A FUNCTION OF ELECTRON-DENSITY FOR EXTRAORDINARY WAVE BELOW GYROMAGNETIC FREQUENCY ACCORDING TO LORENTZ THEORY

where

$$a = 8\ (3 \sin^2 I - 1)^3 \tag{11}$$

$$b = 9\ (9 \sin^4 I - 42 \sin^2 I + 1) \tag{12}$$

$$c = 324 \sin^2 I \tag{13}$$

The smaller positive value of y given by (10) is the ratio of the gyromagnetic frequency to the Lorentz frequency. Figure 3 is based on the solution of (10). To find the value of electron-density for which the lateral deviation becomes infinite at the Lorentz frequency we merely have to evaluate the double root of the cubic (7) for x. This is also a root of the quadratic equation $\partial a/\partial x = 0$. We therefore find without difficulty that the electron-density which produces infinite lateral deviation of the extraordinary wave at the Lorentz frequency is given by

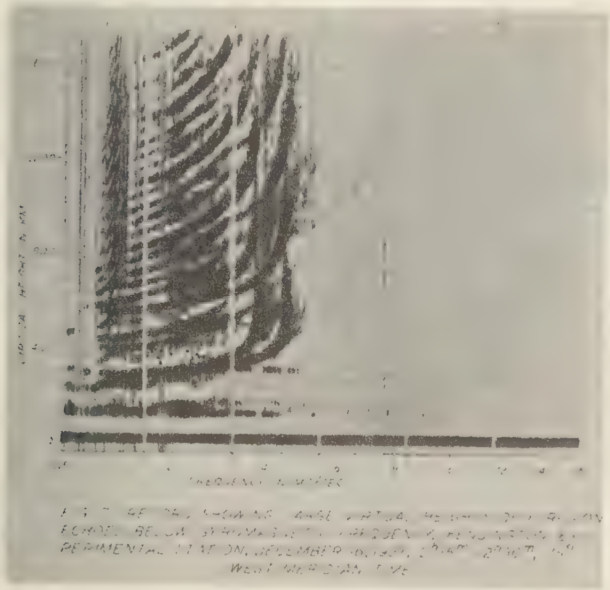
$$N/N_0 = \sqrt{[1 + 2y^2\{\sin^2 I - (1/3)\}]} - 1 \tag{14}$$

where y^2 has the smaller value given by (10). Figure 5 is based upon equation (14). The electron-density given by (14) clearly becomes negative when $\sin^2 I < 1/3$, and it is for this reason the Lorentz frequency loses practical significance when $|I| < \sin^{-1} (1/\sqrt{3})$. It should also be noted that the Lorentz frequency loses significance when $|I|$ is almost 90°. The reason for this is that, when vertical propagation in the ionosphere is quasi-longitudinal at all heights, the extraordinary wave is not reflected at all for wave-frequencies less than the gyromagnetic frequency.

3—*Observations*

Observations bearing upon the above method of deciding between the Sellmeyer and Lorentz theories have been made near Washington, D. C., using the automatic multifrequency technique of vertical radiosounding of the ionosphere [10]. Every quarter of an hour the equipment records the way in which the virtual height of reflection of ionospheric

echoes varies with the oscillation-frequency of the exploring wave. Figure 7 reproduces one of these records. At the lower end of the fre-



quency-range the wave-frequency is less than the gyromagnetic frequency. At this end of the record there can be seen echoes, the virtual heights of which increase with increase of wave-frequency and tend to infinity as the wave-frequency increases to 1.38 mc/sec. If these echoes are due to reflection of the extraordinary wave, then, according to Figures 2 and 3, we should be able to decide between the Sellmeyer and Lorentz theories by comparing the value of the gyromagnetic frequency with 1.38 mc/sec.

The record reproduced in Figure 7 shows echoes reflected from both the E- and F-regions of the ionosphere. In addition to primary echoes there are various multiple echoes, the origin of which is indicated in Figure 8. Since the virtual height of the F-region is not in general an integral multiple of that of the E-region there is no difficulty in identifying

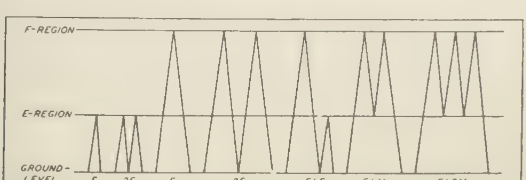


FIG. 8—NOTATION FOR IONOSPHERIC ECHOES

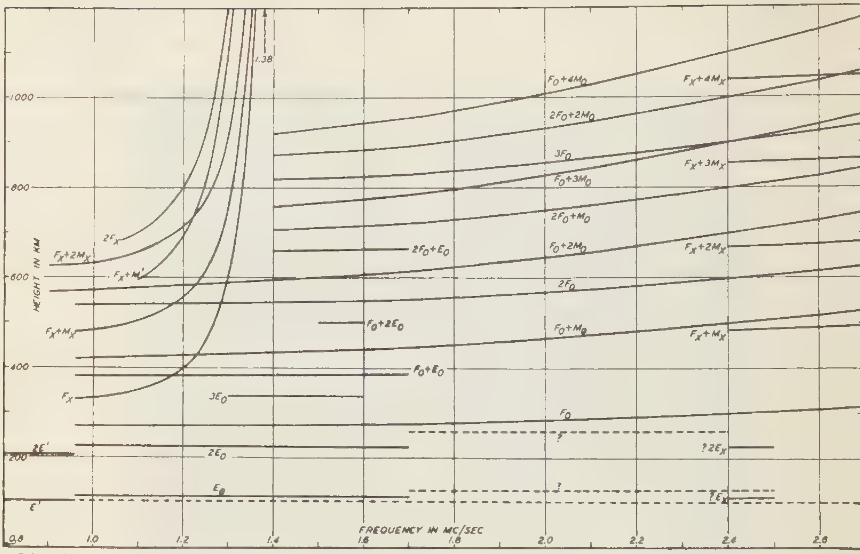


FIG. 9—SKETCH FROM RECORD SHOWING LARGE VIRTUAL HEIGHTS OF F-REGION ECHOES BELOW GYROMAGNETIC FREQUENCY, KENSINGTON EXPERIMENTAL STATION, DECEMBER 16, 1937, 2^h15^m TO 2^h30^m, 75°WEST MERIDIAN TIME

the various echoes. Figure 9 is a sketch of the relevant portion of the record reproduced in Figure 7. It shows the identification of the various echoes, using the notation indicated in Figure 8. There are two primary F-region echoes, marked F_o and F_x. At the lower end of the frequency-range the virtual height of the F_o-echo has practically no dependence upon wave-frequency. That of the F_x-echo on the other hand has a marked dependence upon wave-frequency. It is the virtual height of this echo which increases to infinity as the wave-frequency increases to 1.38 mc/sec. Two of the multiples of the F_x-echo are of particular interest. They are marked F_x+M_x and F_x+2M_x. In addition to having traveled up to the F-region and back again, they have traveled back and forth between the E- and F-regions once and twice, respectively. The additional virtual height resulting from the journey back and forth between the two regions is practically independent of wave-frequency. It does not increase to infinity as the wave-frequency increases to 1.38 mc/sec.

Altogether we have several dozen records showing echoes the virtual heights of which increase markedly as the wave-frequency increases to about 1.38 mc/sec. Some are summer records, some are winter records. All are records at night. On some nights the echoes appear on a series of successive records. On other nights they are not observed at all. When they do appear they are always reflected from the F-region. Echoes of this type have never been observed from the E-region. There is considerable variation in the maximum virtual height to which these echoes can be followed. There is also some variation in the maximum wave-frequency to which they can be followed. However, these two quantities seem to be correlated in such a way as to indicate that there is

little variation in the wave-frequency at which the virtual height actually becomes infinite. This frequency can be determined with some precision from the record reproduced in Figure 7. The echoes can be followed to an unusually large virtual height, and at virtual heights between 1200 and 1600 km it is actually possible to recognize on the record the individuality of the marks which at lower virtual heights merge into a continuous trace. These marks correspond to wave-frequencies which differ by known amounts, and we are able to deduce that, at a wave-frequency slightly less than 1.38 mc/sec, the virtual height is increasing with increase of wave-frequency at about 100 km per kilocycle per second. The accuracy of the frequency-scale was checked against the frequencies of broadcasting stations. We are sure that the wave-frequency at which the virtual height becomes infinite always lies between 1.30 and 1.40 mc/sec. We regard 1.38 mc/sec as its most probable value.

Many of the records show a multiple echo of the $(F_x + M_x)$-type the virtual height of which increases markedly as the wave-frequency increases to about 1.38 mc/sec (compare Figure 9). In all cases the difference between the virtual height of this echo and that of the F_x-echo is practically independent of wave-frequency and shows no tendency to increase to infinity as the wave-frequency increases to about 1.38 mc/sec.

In the record reproduced in Figure 7 and sketched in Figure 9 the lowest frequency at which the F_o-echo is observed coincides with the lowest frequency at which the F_x-echo is observed. This is not always the case however. A record for which the lowest frequency at which the F_o-echo is observed exceeds the lowest frequency at which the F_x-echo is observed is reproduced in Figure 10 and sketched in Figure 11.

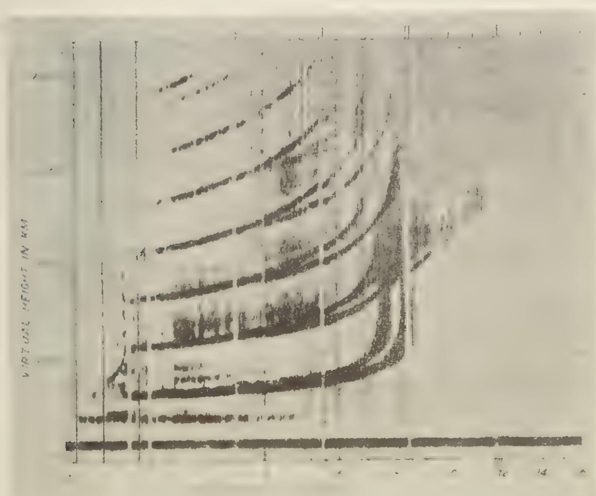


FIG 10—RECORD SHOWING E-REGION STRUCTURE, KENSINGTON EXPERIMENTAL STATION, DECEMBER 24, 1937, $19^h 00^m$—$19^h 15^m$, 75° WEST MERIDIAN TIME

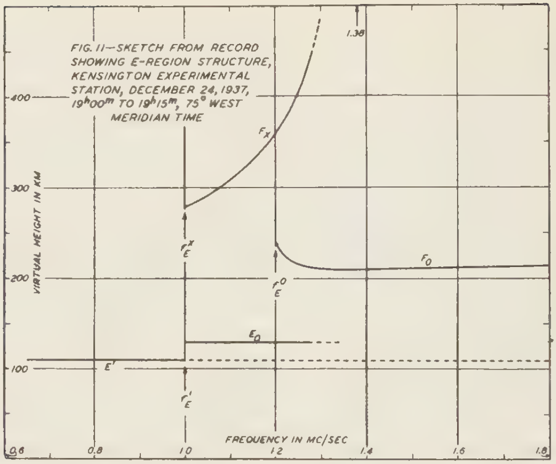


FIG. 11—SKETCH FROM RECORD SHOWING E-REGION STRUCTURE, KENSINGTON EXPERIMENTAL STATION, DECEMBER 24, 1937, 19h00m TO 19h15m, 75° WEST MERIDIAN TIME

It will be noticed that for this record there are, at wave-frequencies between about 1.0 and 1.3 mc/sec, two E-region echoes denoted in Figure 11 by E' and E_o. The highest frequency at which the E_o-echo is observed coincides approximately with the lowest frequency at which the F_o-echo is observed. The lowest frequency at which the E_o-echo is observed coincides with the lowest frequency at which the F_x-echo is observed. For the record reproduced in Figure 7 and sketched in Figure 9 there is also a discontinuity in the virtual height of the $2E$-echo at a wave-frequency of 0.96 mc/sec, and this again coincides with the lowest frequency at which the F_x-echo is observed. There are however some records for which the discontinuity in E-region reflection occurs at a wave-frequency less than the lowest frequency at which the F_x-echo is observed. If we denote by f^o_E and f^x_E the lowest frequencies at which the F_o- and F_x-echoes are observed, and by f'_E the frequency at which discontinuity in E-region reflection occurs, it would seem that we can make the following generalizations. We always have $f'_E \leq f^x_E \leq f^o_E$. The frequency $\{(f^o_E)^2 - (f^x_E)^2\}/f^x_E$ varies between 0 and about 1.5 mc/sec. The larger values of this frequency occur when $f'_E < f^x_E$, and the smaller values when $f'_E = f^x_E$. In a number of records the virtual height of the F_o-echo shows an increase of virtual height with decrease of wave-frequency such as that occurring between 1.3 and 1.2 mc/sec in the record reproduced in Figure 10 and sketched in Figure 11. In these cases we take f^o_E to be the wave-frequency at which the virtual height of the F_o-echo is greatest even though there may be some persistence of the F_o-echo below this frequency.

In order to discriminate between the Sellmeyer and Lorentz theories we shall have to compare the wave-frequency 1.38 mc/sec at which the virtual height of the F_x-echo becomes infinite with the value of the gyromagnetic frequency. The gyromagnetic frequency is proportional to the magnitude of the Earth's magnetic field. To a close approximation this should decrease with increase of height above the ground inversely proportional to the cube of the distance upon the center of the Earth.

At Washington, D. C., the gyromagnetic frequency has the value 1.61 mc/sec at ground-level. Its decrease with increase of height according to the inverse-cube law is shown in Figure 12. There is a radio method

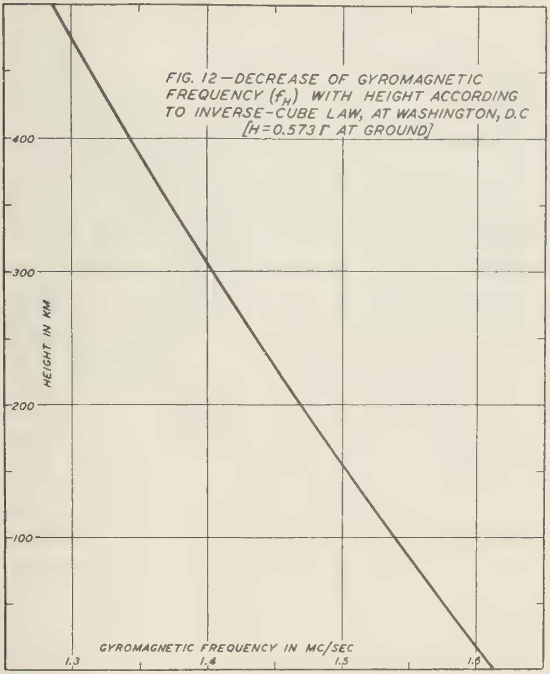


FIG. 12—DECREASE OF GYROMAGNETIC FREQUENCY (f_H) WITH HEIGHT ACCORDING TO INVERSE-CUBE LAW, AT WASHINGTON, D.C [H=0.573 Γ AT GROUND]

[11] of actually measuring the magnitude of the gyromagnetic frequency in the ionosphere. It involves observation of the critical penetration-frequencies of the ionospheric regions for the ordinary and extraordinary waves. Observations of this type near Washington, D. C., by the automatic multifrequency technique, show satisfactory agreement with Figure 12 for both the E- and F-regions. In the case of the E-region the average of 41 observations gave a value for the gyromagnetic frequency at the level of maximum electron-density in the E-region between 1.50 and 1.51 mc/sec. Twenty of these observations were made in the morning, 20 in the afternoon, and one near midday. This value is likely to be a little less than the true value owing to presence in the E-region of atomic and molecular ions. It is satisfactory to notice therefore that Figure 12 gives a value of the gyromagnetic frequency at a level of 110 to 120 km about 0.02 mc/sec greater than the observed value. We do not think that the dependence of the gyromagnetic frequency upon height given in Figure 12 is in error by more than one or two per cent. We are sure that the value of the gyromagnetic frequency at the level of maximum electron-density in the E-region is greater than 1.50 mc/sec.

4—*Interpretation*

F-region echoes, the virtual heights of which increase markedly with increase of wave-frequency, have been observed at wave-frequencies less than the gyromagnetic frequency not only by ourselves but also by Appleton, Farmer, and Ratcliffe [12], and by Martyn and Munro [13]. But in neither the English nor the Australian observations was it possible to determine the wave-frequency at which the virtual height actually becomes infinite with an accuracy sufficient to decide between the Sellmeyer and Lorentz theories. Appleton, Farmer, and Ratcliffe [12] were however able to observe the elliptical polarization of the downcoming waves. They found that the echoes corresponding to those marked F_o and F_x in Figures 9 and 11 have elliptical polarizations corresponding to the ordinary and extraordinary magneto-ionic components, respectively. It would seem certain therefore that the F_o- and F_x-echoes are due to reflection of the ordinary and extraordinary waves, respectively, from the F-region of the ionosphere. On the other hand, Martyn and Munro [13], who make no mention of having observed the elliptical polarizations of the echoes, interpret the F_x-echo as due to an abnormal reflection of the ordinary wave. We feel that this interpretation is not only inconsistent with the English observations of the elliptical polarization of the echo, but is also inconsistent with the principles of Maxwell's electromagnetic theory.

Since the F_x-echo is due to reflection of the extraordinary wave, and since its virtual height increases to infinity as the wave-frequency increases to 1.38 mc sec, we should now be in a position, according to Figures 2 and 3, to decide between the Sellmeyer and Lorentz theories by comparing the value of the gyromagnetic frequency with 1.38 mc sec. The appropriate value of the gyromagnetic frequency is the value in the retarding stratum, that is, in the stratum responsible for the large virtual height of the F_x-echo at wave-frequencies a little less than 1.38 mc sec. Since Figure 12 shows that the value of the gyromagnetic frequency depends to a significant extent upon height, it is necessary that we determine the height of the retarding stratum. This may be done by considering multiples of the F_x-echo. We have seen that the difference between the virtual height of the (F_x+M_x)-echo (see Fig. 9) and that of the F_x-echo is practically independent of wave-frequency at wave-frequencies less than the gyromagnetic frequency, and does not increase to infinity as the wave-frequency increases to 1.38 mc sec. This means that when the extraordinary magneto-ionic component travels back and forth between the E- and F-regions (see Fig. 8) it does not pass to and fro through the retarding stratum. Consequently the retarding stratum must be below the level of maximum electron-density in the E-region. This is consistent with either the Sellmeyer or Lorentz theory. We saw in Section 2 that for the Sellmeyer theory the retarding stratum is the region of small electron-density. This occurs at the bottom of the ionosphere below the level of maximum electron-density in the E-region. For the Lorentz theory Figure 5 shows that the retarding stratum occurs for larger values of electron-density but nevertheless for values significantly less than that required to reflect the extraordinary wave (which is more than $2N_0$). Even for the Lorentz theory therefore there is no objection to the retarding stratum being located below the level of maximum electron-density in the E-region.

Now we have proved both observationally and theoretically that the value of the gyromagnetic frequency at the level of maximum electron-density in the E-region is greater than 1.50 mc sec. If the gyromagnetic frequency increases with decrease of height, then it is true *a fortiori* that, in the retarding stratum below the level of maximum electron-density in the E-region, the gyromagnetic frequency is greater than 1.50 mc sec. But the wave-frequency at which the virtual height of the F_x-echo becomes infinite is 1.38 mc sec. It follows that this frequency is not coincident with the appropriate value of the gyromagnetic frequency, but is more than 0.1 mc sec less than it. There can be no doubt that this frequency-difference is significant. Consequently the observations described in Section 3 are inconsistent with the Sellmeyer theory. In order to interpret the observations in terms of the Sellmeyer theory it would be necessary to assume that the gyromagnetic frequency varies with height above the surface of the Earth in the following manner. Firstly, there would have to be a decrease from 1.61 mc sec at ground-level to 1.38 mc sec in the retarding stratum. This would imply that the magnitude of the Earth's magnetic field would decrease with increase of height above the ground inversely proportional to an inverse tenth or eleventh power of the distance from the center of the Earth. Secondly, there would have to be a sharp increase in the gyromagnetic frequency from 1.38 mc sec in the retarding stratum to a value greater than 1.50 mc sec at the level of maximum electron-density in the E-region. At greater heights the gyromagnetic frequency could decrease with increase of height inversely proportional to the cube of the distance from the center of the Earth in accordance with the theory of the Earth's magnetic field. It may be mentioned that such an unreasonable distribution of the Earth's magnetic field could not arise from flow in the E-region of the currents responsible for the diurnal variations of terrestrial magnetism. A uniform plane sheet of current produces a magnetic field which is independent of distance from the sheet. Consequently the diurnal variation of the Earth's magnetic field is of the same order of magnitude in the E-region as it is at the surface of the Earth. This is two orders of magnitude too small to be of any help in reconciling the observations of Section 3 with the Sellmeyer theory.

It was mentioned in Section 2 that, on account of absorption, there is significantly less chance in practice of recording large virtual heights of the F_x-echo at wave-frequencies less than the gyromagnetic frequency if the Sellmeyer theory is true than if the Lorentz theory is true. The fact that in the record reproduced in Figure 7 the F_x-echo can be followed to a virtual height as large as 1600 km is therefore a further argument militating against interpretation of the observations in terms of the Sellmeyer theory.

Since the observations of Section 3 seem inconsistent with the Sellmeyer theory, let us attempt to interpret them in terms of the Lorentz theory. According to this point of view the frequency 1.38 mc sec at which the virtual height of the extraordinary wave becomes infinite is the Lorentz frequency f_Λ. This ought to be related to the gyromagnetic frequency f_H in the manner given by (4). We have seen that the value of f_H in the retarding stratum is certainly greater than 1.50 mc sec, and, on the basis of Figure 12, we regard 1.53 mc sec as

its most probable value. The most probable observed value of the ratio of the Lorentz frequency to the gyromagnetic frequency is therefore

$$f_\Lambda/f_H = 0.90 \tag{15}$$

No record could reasonably be interpreted as indicating a value of f_Λ/f_H as great as 0.93. No record requires for its interpretation a value of f_Λ/f_H less than 0.85. There are however some records, such as that reproduced in Figure 7, which do indicate a value of f_Λ/f_H significantly greater than 0.85. Thus, while the observed ratio of the Lorentz frequency to the gyromagnetic frequency is unquestionably less than unity, it does not seem small enough to agree satisfactorily with the theoretical value 0.85 given by (4).

There seem to be three possible explanations of the quantitative discrepancy between (4) and (15). In the first place the magnetic dip in the retarding stratum might be less than at the surface of the Earth. Figure 3 shows that the theoretical ratio of f_Λ to f_H would agree with (15) if the magnetic dip in the retarding stratum were 65°. This is between 6° and 7° less than at ground-level, and would imply that the rate of change of magnetic dip is an order of magnitude greater vertically than it is horizontally. It is true that the theory of the Earth's magnetic field does indicate some decrease of magnetic dip with increase of height at Washington, D. C. But it should not decrease below about 68° even at heights large compared with the radius of the Earth. The possibility that the magnetic dip has the value 65° at a height of only about 100 km is therefore remote and may be rejected. Any slight decrease in the effective value of magnetic dip resulting from decrease of magnetic dip with increase of height is likely to be counterbalanced by a slight increase resulting from lateral deviation of the extraordinary magneto-ionic component towards the nearer magnetic pole (compare Fig. 4).

Another possible explanation of the quantitative discrepancy between (4) and (15) is that the value of l in (1), although differing significantly from zero, is nevertheless not quite as large as 1/3. A third possibility is that there are enough atomic and molecular ions in the retarding stratum to have an appreciable effect upon the value of the Lorentz frequency. This possibility is worth considering further because there are certain other features of the observations which it seems also capable of explaining.

Equation (4) was deduced on the assumption that it is only the free electrons in the ionosphere which affect the propagation of radio waves. Atomic and molecular ions should also contribute directly proportional to their number per unit-volume and inversely proportional to their masses. Atomic and molecular ions likely to occur in the ionosphere have masses between four and five orders of magnitude greater than the mass of an electron. Consequently the effect of ions is negligible compared with that of free electrons unless the ion-density is several orders of magnitude greater than the electron-density. On account of attachment of electrons to atomic and molecular oxygen it is quite possible [compare Chapman 14, Massey 15] that in the E-region of the ionosphere ions of both signs are much more numerous than free electrons. If present in sufficient quantities, these ions would increase the theoretical ratio of the Lorentz frequency to the electronic gyromagnetic frequency.

We can calculate the relative concentration of ions and electrons required to make the theoretical value of f_Λ/f_H agree with the observed value (15). On account of inertia the effect of the Earth's magnetic field upon the motions of ions may be neglected. The relative concentration of ions and electrons is conveniently represented by the quantity

$$r=\frac{(N/m)_i}{(N/m)_e} \qquad (16)$$

Here $(N/m)_e$ is the ratio of the number of electrons per unit-volume to the mass of an electron, and $(N/m)_i$ is the sum of the corresponding ratios for the various types of ions present. Let μ_i be the refractive index which the medium would have if the ions alone were present and if the effect of the Earth's magnetic field upon their motions were neglected. Then, for the mixture of ions and electrons, (7) is replaced by [compare Goubau 16]

$$\alpha\equiv(1+lx)\{(1+lx)^2-y^2\}-\frac{x}{\mu_i^2}\{(1+lx)^2-y^2\sin^2 I\}=0 \qquad (17)$$

If we treat (17) in the same way as we treated (7), we can deduce the value of f_Λ/f_H corresponding to any assigned value of r. Conversely we can calculate the value of r required to make f_Λ/f_H agree with the observed value (15). If we do this, we find that the value of r in the retarding stratum must be about 0·3. If the ions are atomic oxygen ions, the mass of an ion is about 3×10^4 times that of an electron. This makes the ion-density in the retarding stratum about 10^4 times the electron-density. From Figure 5 we can deduce that the electron-density in the retarding stratum has to be about 2×10^4 per cc. Consequently, in order to explain the quantitative discrepancy between (4) and (15) as due to the presence of atomic oxygen ions, we would require in the retarding stratum an ion-density of about 2×10^8 per cc. This is of the same order of magnitude as that deduced by Chapman [14] from the dynamo-theory of the diurnal variations of terrestrial magnetism.

It was stated in Section 3 that radio measurements of the value of the gyromagnetic frequency at the level of maximum electron-density in the E-region give a value slightly less than that expected on the basis of Figure 12, and that the discrepancy is likely to be due to presence in the E-region of atomic and molecular ions. These measurements indicate that, at the level of maximum electron-density in the E-region, the value of r is about 0·01 or 0·02. At this level, therefore, the ion-density is not more than about 10^3 times the electron-density [compare Best, Farmer, and Ratcliffe 17]. Consequently, at the level of maximum electron-density in the E-region, the ratio of ion-density to electron-density is at least an order of magnitude less than it is in the retarding stratum. When the F_x-echo is observable at wave-frequencies less than the Lorentz frequency, the maximum electron-density in the E-region is necessarily less than that required to reflect the extraordinary wave at the Lorentz frequency. This is about 2·1 N_0. Also, from Figure 5, the electron-density in the retarding stratum is about 0·6 N_0 at Washington, D. C. Consequently, the maximum electron-density in the E-region cannot exceed the electron-density in the retarding stratum by as much as an order of magnitude. Since, at the level of maximum electron-

density in the E-region, the ratio of ion-density to electron-density is at least an order of magnitude less than it is in the retarding stratum, it follows that the ion-density at the level of maximum electron-density must be less than it is in the retarding stratum. This indicates that the ion-density reaches a maximum in the E-region at a level below that at which the electron-density reaches a maximum. If this is so, the E-region may be thought of as composed of two regions at slightly different levels, the lower one being an ionic E-region and the upper one an electronic E-region. Such a distribution of ionization with height is indicated in Figure 13. The continuous and broken curves represent the variations with height of $(N/m)_e$ and $(N/m)_i$, respectively.

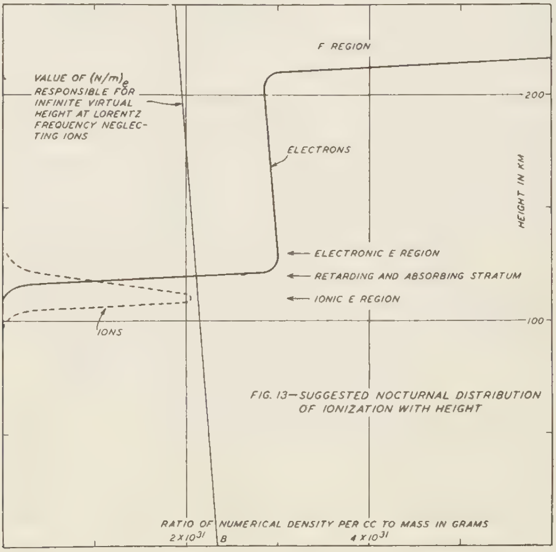


FIG. 13—SUGGESTED NOCTURNAL DISTRIBUTION OF IONIZATION WITH HEIGHT

If, at night, the E-region is indeed composed of an ionic and an electronic E-region as indicated in Figure 13, then the discontinuity in E-region reflection described in Section 3 may be interpreted as due to penetration of the ionic E-region. According to this point of view the wave-frequencies $f^o{}_E$ and f'_E defined in Section 3, and indicated in Figure 11, are, respectively, the critical penetration-frequency of the electronic E-region for the ordinary wave and the critical penetration-frequency of the ionic E-region. For the record reproduced in Figure 10 and sketched in Figure 11, the critical penetration-frequency of the electronic E-region for the ordinary wave is $f^o{}_E = 1.2$ mc sec, approximately. The corresponding critical penetration-frequency of the electronic E-region for the extraordinary wave, assuming that the effect of ions at the level of maximum electron-density in the E-region is small as indicated in Figure 13, is a root of the quadratic equation

$$f\,(f+f_H) = (f^o{}_E)^2 \tag{18}$$

for f. This gives about 0.7 mc sec. But this frequency is less than 1.0 mc/sec, which, according to our interpretation of Figure 11, is the critical penetration-frequency f'_E of the ionic E-region. The complete interpretation of Figure 11 would therefore seem to be as follows. At wave-frequencies less than 1.0 mc/sec the incident wave-packet is reflected from the ionic E-region giving the echo marked E'. No appreciable double refraction takes place in the ionic E-region. At 1.0 mc sec the wave-packet penetrates the ionic E-region. It then enters the electronic E-region and is magneto-ionically split into an ordinary and an extraordinary component. The extraordinary component passes through the retarding stratum above the level of maximum ion-density but below the level of maximum electron-density in the E-region. Now the critical penetration-frequency of the electronic E-region for the extraordinary wave is less than the critical penetration-frequency of the ionic E-region. Consequently, immediately the waves penetrate the ionic E-region, the extraordinary wave is reflected from the F-region, giving the echo marked F_x. The ordinary wave on the other hand is reflected from the electronic E-region giving the echo marked E_o. At about 1.2 mc/sec the ordinary wave penetrates the electronic E-region and is thereafter reflected from the F-region, giving the echo marked F_o. The broken lines indicate scattered echoes. The distribution of ionization with height indicated in Figure 13 is drawn to correspond with this interpretation of Figure 11.

It is interesting to notice that, if this interpretation of Figure 11 is correct, we have a powerful means of studying the distribution of ionization with height in the E-region. Measurement of the Lorentz frequency and the critical penetration-frequencies of the ionic and electronic E-regions gives information about both the ion-density and the electron-density at three different levels in the E-region. These are the level of the retarding stratum and the levels of maximum ion-density and maximum electron-density.

The above interpretation of Figure 11 suggests explanations of several features of the observations described in Section 3. It explains why the lowest frequency at which the F_x-echo is observed often coincides with the wave-frequency at which discontinuity in E-region reflection occurs. It explains why, on such occasions, the lowest frequency at which the F_x-echo is observed exceeds that which would be calculated on the basis of (18) from the critical penetration-frequency of the E-region for the ordinary wave. It also helps to explain why we have never observed E-region echoes whose virtual heights increase markedly with increase of wave-frequency at wave-frequencies less than the gyromagnetic frequency. For, when the critical penetration-frequency of the electronic E-region for the extraordinary wave as given by (18) is less than the critical penetration-frequency f'_E of the ionic E-region, regular reflection of the extraordinary wave from the electronic E-region is impossible at wave-frequencies less than the gyromagnetic frequency.

From multiple echoes of (F_x+M_x)-type (see Figs. 8 and 9) we have seen that, when the extraordinary magneto-ionic component travels back and forth between the electronic E-region and the F-region, it does not pass to and fro through the retarding stratum. This means that the retarding stratum is below the level of maximum electron-density in the E-region, as shown in Figure 13. It also means that the

electron-density between the E- and F-regions cannot be much less than the maximum electron-density in the E-region. Figure 5 gives the electron-density which produces infinite virtual height of the F_x-echo at the Lorentz frequency neglecting the effect of atomic and molecular ions. The corresponding value of $(N/\mathrm{m})_e$ for Washington, D. C., is represented in Figure 13 as a function of height by the curve AB. The dependence upon height arises from dependence of the gyromagnetic frequency upon height given in Figure 12. When the effect of ions is taken into account, the curve AB is modified slightly in the ionic E-region. Because the retarding stratum is below the level of maximum electron-density in the E-region, it follows that the curve representing $(N/\mathrm{m})_e$ as a function of height in Figure 13 must cross the curve AB before reaching the level of maximum electron-density in the E-region. Because there is no stratum of abnormal retardation above the level of maximum electron-density in the E-region, it follows that the $(N/m)_e$-curve cannot recross the curve AB in Figure 13 above this level. At the times of the observations the maximum electron-density in the E-region was never much greater than that given by the curve AB. Consequently, the electron-density between the E- and F-regions must have been nearly as great as the maximum electron-density in the E-region.

The records for December 16, 1937, show the unusual phenomenon of two separate echoes both of which seem to be due to passage of the extraordinary magneto-ionic component up to the F-region, down to the E-region, back to the F-region, and down to the ground. In Figure 9 one of these is marked F_x+M_x and is the echo we have already discussed. For this echo the extraordinary magneto-ionic component, in traveling back and forth between the E- and F-regions, has not passed to and fro through the retarding region. The other echo, which is quite uncommon, is marked $F_x+\mathrm{M}'$. Its variation of virtual height with wave-frequency indicates that for this echo the extraordinary magneto-ionic component did pass through the retarding stratum in traveling back and forth between the E- and F-regions. Our interpretation of this phenomenon is that for the (F_x+M_x)-echo the extraordinary wave traveled back and forth between the F-region and the electronic E-region, whereas for the (F_x+M')-echo it traveled back and forth between the F-region and the ionic E-region. If this interpretation is right, it confirms the hypothesis that there is a level of maximum ion-density in the E-region below the level of maximum electron-density, and that the retarding stratum for the extraordinary wave at wave-frequencies just less than the Lorentz frequency is located between these two levels as shown in Figure 13.

It was indicated in Section 3 that, for a number of records, the F_o-echo persists to wave-frequencies less than that which, on the basis of variation of virtual height with wave-frequency, we interpret as the critical penetration-frequency of the E-region for the ordinary wave. It is possible that this phenomenon is due to breakdown in independence of propagation of the magneto-ionic components in the E-region. Such breakdown is to be expected at large values of magnetic dip as a result of transition in vertical propagation from quasi-tranverse to quasi-longitudinal type [compare Booker 18, 19, 20, 21]. This phenomenon would be accentuated by an unusually sharp gradient of electron-density in the E-region. The phenomenon appears to be quite marked in the record reproduced in Figure 7 and sketched in Figure 9. The

(F_x+3M_x)- and (F_x+4M_x)-echoes show that the critical penetration-frequency of the electronic E-region for the extraordinary wave at wave-frequencies greater than the gyromagnetic frequency is about 2.4 mc/sec. The critical penetration-frequency of the electronic E-region for this wave at wave-frequencies less than the gyromagnetic frequency should differ from this by about 1.5 mc/sec, which is the approximate value of the gyromagnetic frequency at the level of maximum electron-density in the E-region. This frequency is therefore about 0.9 mc/sec. This is slightly less than 0.96 mc/sec, which we interpret as the critical penetration-frequency of the ionic E-region. If the critical penetration-frequencies of the electronic E-region for the extraordinary wave are about 2.4 mc/sec and 0.9 mc/sec, then that for the ordinary wave should be about 1.5 mc/sec. Actually the F_o-echo persists below 1.5 mc/sec right down to the critical penetration-frequency of the ionic E-region. In this particular record the only evidence that the critical penetration-frequency of the electronic E-region for the ordinary wave should be about 1.5 mc/sec seems to be a discontinuity in the virtual height of E-region echoes at about 1.7 mc/sec.

The variation with wave-frequency of the virtual height of the F_x-echo at wave-frequencies less than the Lorentz frequency seems always roughly the same. If we compare this with the theoretical variation for the Lorentz theory given in Figure 2, which is drawn for a linear increase of electron-density with increase of height, we can estimate the gradient of electron-density in the retarding stratum. This is found to be consistent with a distribution of ionization with height in which the major increase of electron-density in the E-region takes place in a height-range of about 10 km. The thickness d of the retarding and absorbing stratum is thus only a few kilometers. Using a value of d in (6) of this order of magnitude, we can deduce that the value of the collisional frequency for electrons in the retarding and absorbing stratum is between 10^4 and 10^5 per sec [compare Best and Ratcliffe 22]. The considerable differences occurring from night to night in the amplitude of F_x-echoes at wave-frequencies less than the Lorentz frequency can easily be accounted for by differences in the thickness of the retarding and absorbing stratum arising from slight differences in the distribution of ionization with height.

We may sum up by saying that the observations of Section 3 we have been unable to interpret in terms of the Sellmeyer theory. But they can be satisfactorily interpreted in terms of the Lorentz theory, and this interpretation indicates a nocturnal distribution of ionization with height of the form shown in Figure 13.

5—*Theoretical considerations*

Some remarks upon the theoretical aspect of the problem of evaluating l in (1) may not be out of place. Following Darwin [2], let us consider a spherical distribution of ionized gas. Suppose that there is incident upon the sphere a linearly polarized electromagnetic wave of wave-length large compared with the linear dimensions of the sphere. Each charged particle in the gas is acted on by an average force per unit-charge which may be regarded as composed of two parts. Firstly, there is the electric intensity of the incident wave. Secondly, there

is the force per unit-charge exerted on the charge by all the other charges. The problem is to calculate this second contribution. Writers prior to Darwin have taken the view that the result cannot be affected by the random motions of the charged particles. Consequently they have reduced the problem to the semi-statical one of calculating the electric intensity **F** due to an isotropic spherical distribution of particles (charge e, N per unit-volume) at a point within the sphere. If **r** is the position vector of the point with respect to the center of the sphere, the question at issue is whether

$$\mathbf{F}=\frac{4}{3}\pi Ne\,\mathbf{r} \quad \text{(the Sellmeyer theory)} \tag{19}$$

or

$$\mathbf{F}=0 \qquad \text{(the Lorentz theory)} \tag{20}$$

The argument in favor of (19) is that charges outside the sphere of radius r concentric with the spherical distribution of particles should give no contribution to **F**, while charges inside the sphere of radius r should give the same contribution as if they were concentrated at the center of the sphere. This is only legitimate as an argument in favor of (19) provided r is large compared with the distance

$$a=N^{-1/3} \tag{21}$$

which we shall call the mean distance between adjacent particles. When r is small compared with the mean distance between adjacent particles, one might expect (19) would be replaced by (20) because of the lack of charge inside the sphere of radius r.

The argument in favor of (20) is the following. The value of **F** at the center of an isotropic spherical distribution of charged particles is obviously zero. Giving the point at which we measure **F** a displacement **r** is clearly equivalent to giving each particle of the spherical distribution a displacement $-\mathbf{r}$. The required value of **F** is therefore the electric intensity at the center of an isotropic spherical distribution of electric doublets each of moment $-e\,\mathbf{r}$. This is zero [compare Lorentz 23], provided we assume that the electric field of every doublet is the same as that of a mathematical point doublet. This argument is only legitimate provided r is small compared with the mean distance between adjacent particles. When r is large compared with the mean distance between adjacent particles, the doublets in the immediate neighborhood of the point at which we are evaluating **F** are being viewed from a distance *small* compared with their length. The assumption that their electric fields are the same as those of mathematical point doublets is therefore invalid, and one would expect **F** to have a value such as that given by (19).

The semi-statical approach to the problem therefore leads to the conclusion that the relation between the magnitude of the force **F** and the magnitude of the displacement **r** should be of the form shown in Figure 14. For values of r large compared with the mean distance a between adjacent particles the relation between F and r is given by (19), and is represented in Figure 14 by the broken line. For values of r small compared with a the relation between F and r is given by (20), so that the (F, r)-curve in Figure 14 is tangent to the r-axis at the origin. For values of r comparable with a, F is a non-linear function of r, as

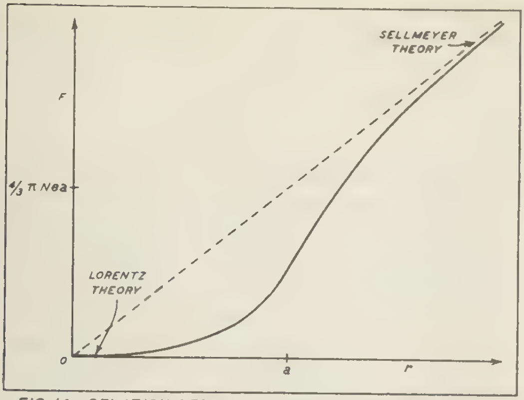


FIG. 14—RELATION BETWEEN FORCE AND DISPLACEMENT FOR AN ELECTRON ACCORDING TO SEMI-STATICAL ARGUMENT

indicated in Figure 14. The semi-statical solution of the problem is therefore the following. The Sellmeyer theory should hold good when the amplitude of vibration of electrons is large compared with the mean distance between adjacent electrons. The Lorentz theory should hold good when the amplitude of vibration is small compared with the mean distance between adjacent electrons. The relation between force and displacement for an electron should be non-linear when the amplitude of vibration is comparable with the mean distance between adjacent electrons.

It is sometimes stated that the semi-statical approach to the problem is ambiguous because one argument leads to (19) whereas another leads to (20). It is quite clear however that (19) and (20) are based on different idealizations. They are both correct, but (19) applies when the amplitude of vibration of electrons is large compared with the mean distance between adjacent electrons, and (20) when it is small. We feel convinced that all semi-statical arguments leading to (19) assume, explicitly or implicitly, that the amplitude of vibration of electrons is large compared with the mean distance between adjacent electrons. We feel equally convinced that all semi-statical arguments leading to (20) assume, explicitly or implicitly, that the amplitude of vibration of electrons is small compared with the mean distance between adjacent electrons. The semi-statical solution of the problem is quite unambiguous and is as indicated above.

It is interesting to compare the conclusion reached by the semi-statical approach with the results of observations. For conduction-electrons in metals under the influence of the alternating electric fields ordinarily encountered in electrical engineering, the amplitude of vibration is large compared with the mean distance between adjacent electrons. Consequently the Sellmeyer theory should hold good in these cases, and this agrees with observation. On the other hand, in insulators, for which the electrons are bound in separate atoms, the amplitude of vibration of electrons is small compared with the mean distance between

adjacent electrons. Hence the Lorentz theory should hold good, and this again agrees with observation. For reflection of medium-frequency and high-frequency radio waves from the ionosphere, the amplitude of vibration of electrons is also small compared with the mean distance between adjacent electrons even for high-power transmitters. Consequently the Lorentz theory should hold good, and this agrees with the observations of Section 3. For radio waves of lower frequency, however, the amplitude of vibration of electrons is liable to become comparable with the mean distance between adjacent electrons. According to the semi-statical argument, this would bring into play the non-linear relationship between force and displacement for an electron, and would cause interaction between radio waves of different frequencies. Such an interaction-phenomenon has in fact been observed, but has already been explained in another way [see Bailey and Martyn 24].

We are aware the semi-statical approach to this problem, even in the form given, has serious shortcomings. As emphasized by Darwin [2], it is essential that account be taken of the random motions of electrons and their collisions with other particles before a convincing solution of the problem can be reached. Nevertheless, in view of what has been said above, it seems worth while drawing serious attention to the possibility that the question of whether it is the Sellmeyer or Lorentz theory which holds good for an ionized gas may have to be answered by saying that one theory holds good under some circumstances and the other theory under other circumstances. The actual nature of the transition from one theory to the other, and the conditions under which it takes place, need to be investigated dynamically.

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INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS MEETING IN WASHINGTON, SEPTEMBER 4-15, 1939

International Association of Terrestrial Magnetism and Electricity

A. H. R. GOLDIE, *Secretary*

Provisional outline of the discussions

I—Address of President: *Trends of Research in Terrestrial Magnetism and Electricity* (Friday, September 8, at 14.30)
II—Report of Secretary and Director of Central Bureau
III—Report of Dr. van Dijk on the publication of numerical magnetic character of days
IV—Finances
V—Election of officers of the Association
VI—National reports
VII—Reports of Committees and Reporters appointed at the Edinburgh Assembly
VIII—Polar Year 1932-33 (1) Report on the activity of the Polar Year Commission of the International Meteorological Organization; (2) Discussion of International Polar Year results
IX—Communications on miscellaneous subjects
X—Subjects for discussion during the Assembly
XI—Subjects for joint discussion with the Association of Meteorology
XII—Subjects for deliberation by Committees (subjects requiring world-wide cooperation in work being done or planned)
XIII—Appointment of Committees and Reporters
XIV—Resolutions

National Reports

These reports, received through National Committees or through the International Commission of Terrestrial Magnetism and Atmospheric Electricity, are intended to describe the activity of the various countries since 1936. The Central Bureau will multigraph reports received before May 31, 1939, and distribute them in Washington; only short abstracts should be read at the meeting.

Reports of existing Committees and Reporters

Committees: (1) On the selection of sites of new observatories for terrestrial magnetism and electricity
(2) On aurora
(3) On the study of the relationship between solar activity and terrestrial magnetism
(4) On magnetic secular-variation stations
(5) On the study of electrical characterization of days
(6) On magnetic charts—(a) Organization of the work, and (b) Methodology
(7) On registration in Iceland of giant pulsations
(8) On methods of observatory publication
(9) On classification of magnetic literature
(10) To promote international comparisons of magnetic standards

Joint Committees: (11) Of the Association and of the International Commission of Terrestrial Magnetism, on methods and codes to adequately describe magnetic disturbances and perturbations

(12) Of the Association and of the International Scientific Radio Union

Reporters: (13) Dr. Crichton Mitchell on numerical magnetic characterization of days

(14) Professor Chapman on international collaboration for promoting the study of the influence of the Moon on geophysical phenomena

(15) Dr. Wait on ion-counters

Communications

Communications dealing mainly with international aspects are specially invited. Such communications will by preference be printed in the *Transactions* of the Association and brief abstracts may be read at the meeting. Copies of the abstracts intended to be read, or summaries, should be sent to the Secretary at the Central Bureau at the earliest possible date. Alternatively, the author may, at his own cost, supply up to 100 printed or cyclostyled extenso copies.

Joint discussion with the Association of Meteorology

The joint discussion will take place probably on September 14. The following subjects have been suggested:

(a) Thunder-storms and the electricity of the lower atmosphere

(*b*) Upper atmospheric physics, including the meteorological and magnetic aspects of solar and terrestrial relationships

Proposals for the agenda

National Committees are reminded that they have the right to submit subjects for discussion, and they are cordially invited to do so. According to the Statutes of the Association, the agenda—including these subjects and any other questions proposed by the Executive Committee—shall be prepared by the Secretary and circulated to members of the General Assembly not less than four months before the opening of the Assembly. Notice of all subjects to be placed on the agenda should thus be received at the Central Bureau, 6 Drumsheugh Gardens, Edinburgh, as early as practicable and, if possible, before April 15, 1939.

Attendance at Washington

Information regarding general arrangements at Washington is given in the circular issued on April 9, 1938, by the American Geophysical Union in cooperation with the National Research Council. Dr. J. A. Fleming, President of our Association, is General Secretary of the American Organizing Committee. Delegates who propose to attend and wish to receive further notices are requested to notify him without delay at 5241 Broad Branch Road, Northwest, Washington, D. C., U. S. A., and also to notify the Secretary of the Association.

Edinburgh, Scotland, November 1938.

IONOSPHERIC MEASUREMENTS AT CENTRAL CHINA COLLEGE, WUCHANG, CHINA, OCTOBER 1937 TO JUNE 1938

By P. L. Sung and C. T. Kwei

Abstract—A brief description is given of a manually operated ionospheric equipment with which a single operator can take necessary readings of virtual heights and critical frequencies. Data for noon-hour runs from October 1937 to January 1938 and from April to June 1938, and half-hour evening-runs in March and April, 1938, are arranged in two tables. Sample and average diurnal-variation curves for virtual heights and critical frequencies are plotted. It is found that the critical frequencies at Wuchang are higher than those at Washington for both the E- and F_2-layers during the same months. The E-layer critical frequency, as is the case elsewhere, reaches a maximum near the local noon, whereas for the F_2-layer the critical frequency reaches a high value about 14^h and maintains nearly the same value till about 17^h, 120° east meridian time. When plotted month by month, the E-layer critical frequency increases with the approach of summer, while the F_2-layer critical frequency tends toward a minimum in July with two probable maxima in October and April. This would make the Wuchang seasonal characteristics approximate those of Watheroo rather than of Washington, but it must be emphasized that data are insufficient to make this point definite. Very often the E-layer virtual height undergoes a dip when a higher layer begins to appear and continues to keep its normal height long after the upper layer has appeared. In a few cases, the E-layer echoes persist even after the F- or F_2-layer has been penetrated. Magnetic splitting is quite evident, especially for the readings during daylight. The observed mean value of 620 kc, as the difference between the o-component and the x-component of the F_2-layer penetrating frequency, checks very well with the theoretical value of 614 kc. A case is reported of a chain of closely packed echoes (scattered reflections) following the first echo from the F-layer on April 2 between $22^h 30^m$ and midnight, 120° east meridian time (or $14^h 30^m$ to 16^h GMT). It is interpreted to be a multiple-reflection phenomenon, when the two F-layers are approaching each other to form one layer in an unsteady fashion.

The manually operated equipment used in making the ionospheric observations reported in this article was designed by L. V. Berkner of the Carnegie Institution of Washington after a scheme proposed by T. R. Gilliland of the National Bureau of Standards, Washington, D. C. This outfit was installed in the Physics Department of Central China College[1] in the fall of 1937. A schematic diagram is shown in Figure 1. Pulses from 7 to 50 per second are produced by the thyratron-unit, which automatically operates a fixed intermediate-frequency oscillator of about 470 kc per sec. Above this unit is placed a variable-frequency oscillator capable of producing oscillations from 1000 to 16,600 kc per sec. The fixed frequency beats with the variable frequency to produce two side bands in a fully balanced modulator which permits only one side band to go through. This last frequency f_V is amplified through a power-amplifier and is finally radiated through one of three different antennas, all of which are Hertzian dipoles at 120, 45, and 30 meters, respectively. The shortest antenna is of cage-form, one meter in diameter, and made of six wires in parallel. The echoes from the ionospheric layers are received by the antenna which also radiates the waves, which in going through the detector beat with $f_V \pm f_I$ from the variable oscillator to

[1]In the city of Wuchang, Hupeh Province, China, in longitude 114° 21′ east and latitude 30° 34′ north.

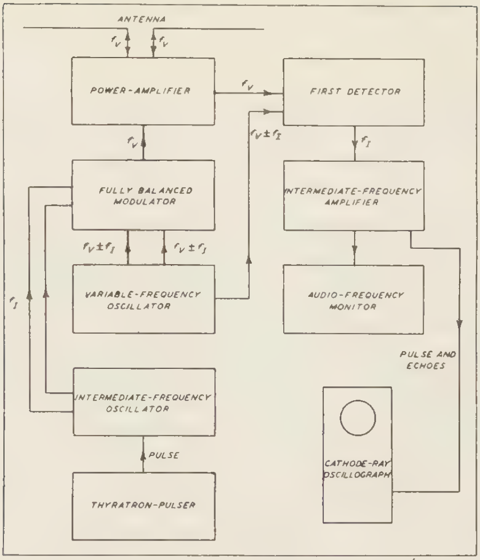


FIG. 1—SCHEMATIC DIAGRAM OF IONOSPHERIC EQUIPMENT USED AT CENTRAL CHINA COLLEGE, WUCHANG, CHINA

produce again the intermediate frequency f_I. The intermediate-frequency amplifier further magnifies the pulse and its echoes, so that they may be heard from the loud-speaker and the virtual heights may be read on a calibrated scale of the cathode-ray oscillograph directly in kilometers.

The run was usually started at a frequency of about 1600 kc and continued at selected steps of 100 to 500 kc each, noting the virtual height at each frequency until $f^x_{F_2}$ was reached, that is, when no echoes were returned at the highest frequency. The frequency versus virtual-height curves were then plotted for each run and the results analyzed according to the standard procedure adopted by the Department of Terrestrial Magnetism, Carnegie Institution of Washington.

Noon-hour runs ending at 13^h (nearest hour), 120° east meridian time (or $12^h\ 37^m$, local mean time), were made nearly every week-day from October 4, 1937, through January 21, 1938, except for interruptions due to air raids or other disturbances affecting our power-source as a consequence of war. The power during the day was irregular after December 1, 1937, and was entirely cut off after January 21, 1938, to conserve fuel. During this period six whole day-runs were made from $8^h\ 30^m$ to 17^h, 120° east meridian time (unless specified otherwise, the time hereafter is 120° east meridian). From March 20 through April 23, regular evening-runs of one-half hour duration were made, mostly ending at about 20^h or 21^h. Six series of longer runs, extending from $18^h\ 40^m$ to midnight when the power was cut off, were made in the month of April. Noon-readings were resumed on April 25 through June 17, 1938, when power was again available during daylight. The results of the noon-hour runs are tabulated in Table 1 and the half-hour evening-runs in Table 2.

TABLE 1—*Ionospheric data, October 4, 1937, to January 23, 1938, and April 25 to June 16, 1938, Wuchang, China*

(All runs end at 13ʰ (nearest hour), 120° east meridian time; the h's represent the lowest virtual heights and the f's the critical frequencies; subscripts designate the layers concerned while superscripts o and x refer to the ordinary component and the extraordinary component of the penetrating ray, respectively.)

Date	h_E	h_{F_1}	h_{F_2}	f_E	f_{F_1}	$f^o_{F_2}$	$f^x_{F_2}$
1937	*km*	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*
Oct. 4	100	260	420			15.4	
6		280	340			15.4	
8			360			15.2	
13	90	190	270	3.5		14.2	
14	90	230	330	3.4		15.0	
18	100		350			15.8	
19	120	250	340			15.0	
20	110	220	300	3.2		14.6	15.2
21	120	240	320	4.0		15.4	16.0
22	110	210	300	4.0		15.7	16.3
23	110	210	320	4.1		15.1	15.7
26	120	230	330	4.2		15.7	16.3
27	100	230	330	4.0		15.8	16.3
28	100	230	330	4.0		15.3	15.9
29	120	220	330	4.0		15.2	
30	110	240	320	4.0		15.2	15.8
Nov. 1	110	260	330	4.5		14.4	
2	110	260	320	5.1		15.6	16.2
3	110	210	330	4.2		15.7	16.3
4	110	260	310	4.5		15.1	15.7
5	120	250	360	3.3		15.6	
6	120					14.8	15.4
8	120	240	300	3.9		14.8	15.4
10	110	250	300	4.0		14.3	15.0
16	110	240	280	4.0		14.2	14.8
17	110	230	280	4.5		14.7	
18	100	260	280	3.9		14.8	15.4
19	120	260	290	4.5		14.2	
20	100	220	300	3.3		15.1	15.7
23	110	250	330	4.0		13.6	
24	110	230	320	4.0		14.2	14.8
25	110	230	290	3.6		12.8	13.4
26	110	240	310	3.9		13.4	14.0
27	110	210	290	3.9		13.1	13.9
30	110	230	300	3.9		15.4	16.0
Dec. 1	110	220	340	3.6		13.8	14.4
2	110	240	310	4.0		14.4	15.0
4	100	230	290	4.2		15.4	15.0
6	100	250	300	4.2		15.2	15.8
16	110	210	290	4.2		13.6	
21	110	240	270	4.0		12.2	12.8
22	100	220	300	3.7		12.8	13.4
29	110	230	320			11.2	
30	100	240	270			13.7	14.3

From the data in Table 1, the mean day of each month for all actual days of observation is plotted against the corresponding virtual heights of the layers in Figure 2-*A*. It is seen that the E- and F_1-layers have nearly constant virtual heights during the noon-hour at Wuchang. There is a drop in the F_2-layer virtual height from October to January and a tendency to rise as the summer months are approached. There

Table 1—*Ionospheric data, October 4, 1937, to January 23, 1938, and April 25 to June 16, 1938, Wuchang, China*—Continued

Date	h_E	h_{F_1}	h_{F_2}	f_E	f_{F_1}	$f^0{}_{F_2}$	$f^x{}_{F_2}$
1938	*km*	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*
Jan. 3	110	220	290	3.7		12.6	13.2
4	120						
5	100	220	260	3.9		14.5	
11	110	220	280	3.9		12.4	13.0
12	110	250	250	4.3		13.2	13.8
13	100	220	260	3.9		12.4	13.0
14	120	250	300			12.6	13.2
15	100	220	240	3.9		12.9	13.6
17	110	240	330	4.0		12.2	12.8
19	120	240	290	4.0		15.8	16.4
20	110	230	320	3.0		13.8	14.5
21	100	240	300	4.0		12.9	13.6
Apr. 25	100		350	6.0		16.0	16.6
26	130		340	5.3		14.4	15.0
27	110	260	360	5.0		15.4	16.0
28			350			14.4	15.0
29	110		350			15.0	15.8
30	100		330			15.8	16.4
May 2	110		330	6.2		15.8	16.2
4	110		350	6.0		13.8	14.4
5	110		350			13.6	14.2
6	110		340	4.5		13.6	14.2
7	110		360	5.7		13.6	14.4
9	100		340			13.0	13.6
12	100		390	6.0		10.5	11.2
13	110		370	6.0		13.8	14.4
16	100		360	5.7		14.2	14.8
17	110	230	370	5.0		11.8	12.6
19			330			12.0	12.7
20	*100*		*250*	*13.0*		*10.6*	
24	120		350	5.2		11.8	12.6
26	110		350	6.5		12.4	13.0
27	100		390	5.6		12.2	12.8
28	100		400	5.8		12.4	13.2
30	100		370	7.0		12.6	13.2
June 1	100		400	5.0		12.0	12.6
2	100		380	6.0		12.2	
4	100	230	380			12.6	13.2
6	100	200	380	4.0		11.6	12.4
7	*100*		*230*	*16.4*		*10.2*	
9	*100*		*400*	*14.0*		*12.2*	*12.8*
10	110		400	6.5		12.2	12.8
11	110		360	5.7		12.8	13.4
15	100		400	6.0		11.6	12.2
17	110		400	5.7			

Note: On May 20, June 7 and 9, it will be noticed that the E-layer remains in evidence at approximately the normal virtual height long after the F-layer has been penetrated. It is interesting to note that under such circumstances there is only one F-layer with comparatively low virtual height. All the F-layers are arbitrarily put under the column of F_2, instead of F_1.

are only four occasions out of a total of 34 observations from April to June when there was a definite F_1-layer, and therefore on account of its sporadic nature this layer may be considered as missing during this period. For comparison, the heights of the layers in Washington for

the corresponding months are plotted.[2] The crosses represent Washington values and the dots the Wuchang values in the Figure. The E-layer

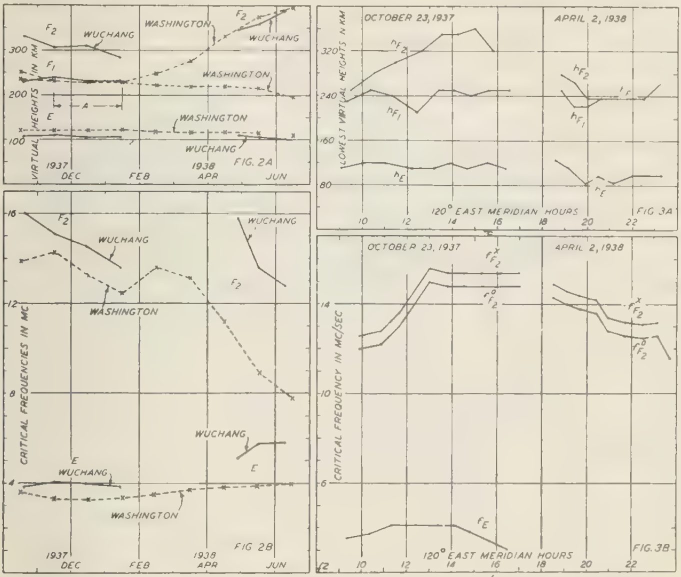


FIG. 2A—MEAN VIRTUAL HEIGHTS OF LAYERS AGAINST MEAN DAY OF MONTH (MEAN DAY IS NOT NECESSARILY MIDDLE OF MONTH FOR WUCHANG, BECAUSE SOME DAYS OMITTED OWING TO DISTURBED CONDITIONS IN CHINA — A = h'_{F_1} AND h'_{F_2} FOR WASHINGTON ARE SAME BECAUSE OF MERGING OF F_1- AND F_2-REGIONS)

FIG. 2B—CRITICAL FREQUENCIES E- AND F_2-LAYERS ARE HIGHER FOR WUCHANG THAN FOR WASHINGTON; WINTER MAXIMUM F_2-LAYER AT WASHINGTON IN NOVEMBER, 1937, AND EARLIER AT WUCHANG; WUCHANG CURVE INDICATES POSSIBLE SECOND MAXIMUM IN APRIL OR MARCH AND MINIMUM IN JUNE OR JULY

FIG. 3A—VIRTUAL HEIGHT, DAYTIME OF OCTOBER 23, 1937, AND EVENING OF APRIL 2, 1938, SHOWING TENDENCY THE TWO F-LAYERS TO COMBINE IN EVENING

FIG. 3B—CRITICAL FREQUENCIES, DAYTIME (OCTOBER 23, 1937) AND EVENING RUNS (APRIL 2, 1938)

is slightly higher at Washington than at Wuchang. The height of the F_1-layer at Wuchang is about the same as that of the F_2- or F-layer at Washington, and that of the F_2-layer at Wuchang is from 50 to 80 km higher than the F_1-layer, with a tendency of merging with the lower layer in February or March. The mean height of the F_2-layer at Wuchang is over 100 km higher in June than in January (289 km as compared with 284 km). [The Washington values for April to June have been added for comparison.]

Figure 2-B gives the variation of critical frequencies with the seasons. There is a distinct drop from October to January and again from April to June for the $f^x{}_{F_2}$-layer frequency, although there are too few readings to make the point in April significant. The E-layer critical frequency is higher in April to June than in October to January. The increase of E-layer critical frequency with the approach of summer months is of course also observed elsewhere.[3] The average of all readings from

[2]The Washington values are taken from reports of the National Bureau of Standards as published in Terr. Mag., **42**, 408-409 (1937), and **43**, 88-89 (1938).

[3]S. S. Kirby, L. V. Berkner, and D. M. Stuart, Proc. Inst. Radio Eng., **22**, 481-521 (1934).

Table 2—*Ionospheric data from March 20 to April 23, 1938, half-hour evening-runs, Wuchang, China*

Date	h_E	h_{F_1}	h_{F_2}	f_E	f_{F_1}	$f^o_{F_2}$	$f^x_{F_2}$
1938	*km*	*km*	*km*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*
Ending at 21h, 120° east meridian time							
Mar. 22		250	290		5.7		13.4
23			280			11.4	12.0
24		220	290		6.0	10.0	10.6
25		220	260		5.0	12.2	12.6
31	110		260			13.4	14.0
Apr. 4	100	250	260		4.2	9.6	10.2
6	110		250				8.0
7	110		290				9.8
9	100		280			13.4	14.2
11	110	250	280				11.0
12	110		280				10.2
13			280			13.6	14.2
14			240				9.6
15	110		270			13.6	14.2
16	110		250				8.5
19	100		280			12.5	13.2
20	110		280			14.4	15.0
Ending at 20h, 120° east meridian time							
Mar. 20	100	250	290	2.0	6.2		15.4
21		210	280	2.0	6.5		15.7
25		210	280		6.5	12.6	13.2
26	100	210	260		4.2	13.0	13.6
Apr. 2	110	220	240	2.5	4.2	12.8	13.4
9	85		250			12.8	13.6
12	100	250	280		3.3		12.0
16	110	250	280		2.5		10.1
19	100		280			12.8	13.6
23	85		250			12.4	13.0
Other evening-runs at irregular hours, not included in long series of run up to midnight							
Mar. 28[a]			220				
31[b]	100	220	280		5.3		
Apr. 1[c]	100	250	280		7.5	13.8	14.4

[a]Ending at 23h 10m. [b]Ending at 19h 12m. [c]Ending at 18h 13m.

October to January is 14,850 kc, while that for April, May, and June is 13,850 kc for the F_2-layer x-component penetrating frequency, which seems to point to a real minimum in July. According to Berkner and Wells' analysis of the data of the Watheroo observations[4] (longitude 116° east, latitude 30° south), there are two maxima in the critical frequencies for the F_2-layer, occurring about the time of the equinoxes, and a distinct minimum occurring in July and a second lesser minimum occurring in January or February. Our insufficient data—further made discontinuous due to war conditions—prohibit drawing any general conditions. But in assuming that the maxima in Wuchang occur in October and April and that a distinct minimum occurs in July, the curve for seasonal or annual variation in Wuchang approximates that of Watheroo rather than that of Washington. Further accumulation

[4]L. V. Berkner and H. W. Wells, Terr. Mag., 43, 15-36 (1938).

of data in a continuous manner will be necessary to decide this point. The Washington values of critical frequencies for this layer from October to January are plotted as crosses in Figure 2-*B*. The Washington winter maximum for 1937 occurs in November, whereas that at Wuchang occurs in October or September. From November to January, the two curves are sensibly parallel with the higher values for Wuchang. The *E*-layer frequencies are also higher for Wuchang than for Washington, evidently on account of the difference in latitude. Washington data are not available for comparison during April to June.

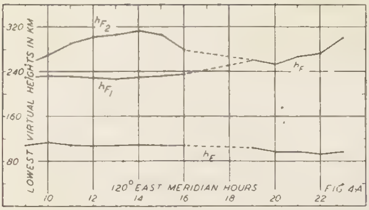
Table 2 contains the data for the evening-runs of half-hour duration in March and April, 1938. It will be noticed that few critical *E*-layer frequencies are given. This is because the higher layers are much more distinct with only sporadic appearances of weak *E*-layer echoes which give us the virtual height without enabling us to determine the critical frequency. On nine out of 30 runs there was no trace of *E*-layer. In these evening-runs it is quite common to find the second or third echo of strong intensity, showing that the absorption is reduced as compared with daytime-signals.[5] It is also evident that during evening hours there is a strong tendency for the two layers to combine into one, since on 14 out of 30 occasions there was separation into two separate layers. The *E*-layer critical frequencies, while few in number, definitely are of a lower value than for daytime-runs. The critical frequencies of the F_1- and F_2-layers are less consistent or predictable, varying through a wider range as compared with the noon-hour runs.

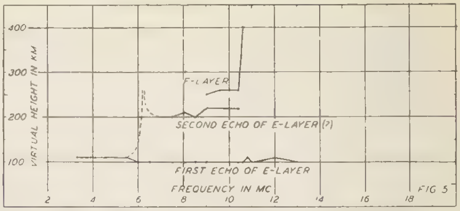
Six diurnal-variation runs were taken during daylight from $8^h\ 30^m$ to 17^h on October 23, 30, November 6, 20, 27, and December 4, 1937, and in the evening from $18^h\ 30^m$ to midnight on April 2, 9, 12, 16, 19, and 23, 1938. The results for October 23 and April 2 are plotted in Figures 3-*A* and 3-*B*, and the average of all six sets of readings both for the day and for the evening are arbitrarily joined together for comparison and are plotted in Figures 4-*A* and 4-*B*. It is seen that the *E*-layer changes little in virtual height either day or night. The F_2-layer increases in height beginning in the morning, reaches a maximum at about 14^h, and decreases in height in the evening to combine with F_1 to form one single layer. The F_1-layer remains nearly constant in height during the day, with a tendency to rise in the evening to form one single *F*-layer. In the critical-frequency curves, the F_1-layer critical frequencies are omitted because of lack of sharp definition. The *E*-layer maximum frequency occurs at about local noon. The F_2-layer maximum is reached between 13^h and 14^h and maintains its value with a very slight increase till the end of the run at 17^h. In the evening, the F_2-layer critical frequency tends to fall and that of the *E*-layer does not appear, which is also the case with the half-hour evening-runs reported in Table 2.

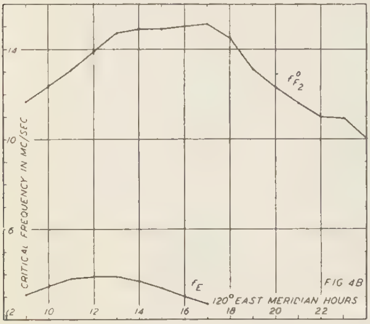
The critical frequency of the *E*-layer is not always sharp. Very often there is a dip in the virtual height of this layer when a higher layer begins to appear. Then the *E*-layer echoes gradually diminish in intensity until they vanish at the normal height, while the *F*-layer echoes gain in intensity. Similar phenomenon was observed by Wells[6] at Huancayo (longitude 75° west, latitude 12° south) and was attributed by him as due to partial reflection at low latitude. There have been

[5]See H. R. Mimno, Rev. Modern Phys., **9**, 1-43 (1937).

[6]H. W. Wells, Terr. Mag., **39**, 209-214 (1934).







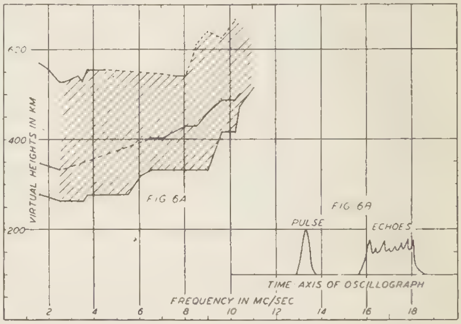


FIG. 4A—VIRTUAL HEIGHTS, AVERAGE DAY RUNS OCTOBER 23, 30, NOVEMBER 6, 20, 27, AND DECEMBER 4, 1937, AND EVENING RUNS APRIL 2, 9, 12, 16, 19, 23, 1938; E- AND F_1-LAYERS MAINTAIN NEARLY CONSTANT VIRTUAL HEIGHTS, WHILE F_2 REACHES MAXIMUM ABOUT 14^h AND DECREASES IN EVENING TO FORM SINGLE F-LAYER

FIG. 4B—CRITICAL FREQUENCIES, AVERAGES DAY AND EVENING RUNS; MAXIMUM FOR E-LAYER ABOUT LOCAL NOON AND F_2-LAYER ABOUT 14^h AND MAINTAINED NEARLY SAME TO 17^h

FIG. 5—PERSISTANCE OF E-ECHOES AFTER F-LAYER HAS BEEN PENETRATED, MAY 20, 1938, 12^h46^m TO 13^h11^m, 120° EAST MERIDIAN TIME

FIG. 6—(A) INDEFINITE POSITIONS OF F-LAYER ECHOES AND (B) TRAIN OF ECHOES OF VARYING AMPLITUDE, APRIL 2, 1938, 23^h15^m TO 23^h43^m, 120° EAST MERIDIAN TIME

a number of cases for both the noon- and evening-readings where the E-layer echoes persist after the F_2-layer has been penetrated. Figure 5 is an illustration in point, as well as the italicized data in Table 2. Epstein[7] has demonstrated that for the case when the dielectric factor of the medium attains a minimum value in a vertical direction and then increases again, partial rather than total reflection should take place. If the ionization-density of the lower layer increases continuously with altitude without a maximum ionized region until reaching a very great height, then the reflection from a lower layer is observed with a constant virtual height as frequency increases, no matter whether or not there is a reflection from an upper layer.

For the F_2-layer magneto-ionic splitting has been quite evident, especially for the day-readings. The theory of magnetic splitting has been treated by a number of authors.[8] Berkner and Wells[9] have shown that for very high frequencies, the difference between the critical frequencies of the ordinary and extraordinary components for the F_2-layer should be $He/4\pi\, mc$, where H is the magnetic horizontal component of the Earth's field. The value of H at Wuchang is 0.434 gauss. Using the value of e/m for electrons in this equation, the difference between

[7] P. S. Epstein, Proc. Nation. Acad. Sci., **16**, 37-45 and 627-637 (1930).

[8] G. Breit, Proc. Inst. Radio Eng., **15**, 709-723 (1927); E. V. Appleton and M. A. F. Barnett, Nature, **115**, 333-334 (1925); E. V. Appleton and M. A. F. Barnett, Proc. R. Soc., A, **109**, 621-641 (1925); and H. W. Nichols and J. C. Schelleng, Bell System Tech. J., **4**, 215-234 (1925).

[9] L. V. Berkner and H. W. Wells, Proc. Inst. Radio Eng., **22**, 1102-1123 (1934).

the two frequencies comes out to be 614 kc, whereas the average of all observed values for 166 sets of observations is 620 kc, which is in excellent agreement with the theoretical value and lends support to the hypothesis that the electrons, not heavier ions, are primarily responsible for magnetic splitting in the F_2-layer.

One more thing worth reporting here is the phenomenon observed on April 2, 1938, from $22^h\ 30^m$ to about midnight. One set of runs is shown in Figures 6-*A* and 6-*B* For a definite position of the pulse on the oscillograph-screen, there is a large train of echoes closely packed together, the train itself varying in amplitude with time. It is difficult to assume that momentarily the ionosphere is divided into numerous layers. It is more reasonable to suppose that there is reflection between adjacent layers near together, producing the phenomenon of multiple reflection, and that there is a rapid shift of one of the layers. This might happen when the two *F*-layers are coming together to form one layer in an unsteady fashion.

The authors are quite aware of the paucity and the discontinuity of their data, but deem it wise to publish the material as it is now, as it has become necessary for them to evacuate Wuchang and there is much uncertainty as to when or how they will be able to continue this work.

Note added to the manuscript: Upon re-examination of our data, it is noted that curves plotted for the diurnal variation showed two distinct *F*-layers only on two occasions out of six whole evening-runs, namely, on April 2 up to $20^h\ 30^m$ and on April 16 up to $20^h\ 40^m$; on both these evenings, trains of echoes were prominent, thus substantiating our supposition that the multiple-reflection phenomenon is probably associated with the approach of the F_1- and F_2-layers to form one single layer.

It is a pleasure for us to acknowledge our gratitude to Dr. J. A. Fleming, Director of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, for making it possible to install the ionospheric equipment in Central China College, to L. V. Berkner and H. W. Wells for their help and advice in designing and constructing the apparatus, to Dr. M. A. Tuve of the same Department, and to Drs. R. P. Bien and David S. Hsiung, our colleagues in Wuchang, for their interest and encouragement in this work.

Department of Physics,
Central China College,
Wuchang, China, July 4, 1938

(See also page 483)

MICHAEL RUTGERS VAN DER LOEFF: *De Ionen en de Ionisatiebalans in de Atmospheer* (*The ions and the ionization balance in the atmosphere*), Dissertation Amsterdam, 1938 (120 pages, 26 figures).

Dr. Rutgers van der Loeff treats the ion-phenomena in the atmosphere both theoretically and experimentally. He considers the common discrimination between large and small ions to be insufficient. The generally adopted difference is due to a subjective classification and the theoretically deduced relations between both kinds of ions have no physical meaning. In the atmosphere we have not to do with small ions with some constant mobility and with large ions having another mobility. Measurements with the Ebert aspirator do not procure the number of small ions only. The "ion-spectrum" is continuous, the mobilities varying from 1 to 10^{-4} cm²/sec/volt. Some mobilities may be rare, but it is not allowed to speak of large and small ions and it is incorrect to substitute the results of measurements with the Ebert aspirator in the ionization-balance of Schweidler. This apparently well-established formula needs a thorough revision and the author deduces a new ionization-balance, in which the conductivity due to the ions of all mobilities enters instead of the number of small ions. His equation is the following,

$$q=\frac{H.C_R}{V}\,\frac{Z_{+}+Z_{-}}{W.C_A}$$

Where q = ionization in pairs of ions/cc/sec; H = the empirical half-value voltage ($1/H$ being proportional to the average life of *all* ions); V = volume of the recombination-vessel in cc and C_R its measured capacity in cm; W = voltage applied to the aspirator and C_A = its capacity in cm; $Z+$ and $Z-$ = the number of ions collected in the aspirator per sec, under the condition that the limiting mobility, $k_0=\phi/4\pi WC_A$, is greater than the greatest of all mobilities represented in the atmosphere (ϕ = air-stream through the aspirator in cc/sec).

By means of measurements with different limiting mobilities it is possible to deduce particulars of the ion-spectrum. To this purpose simultaneous measurements with several aspirators, or average values of sustained observations are necessary. The author had to be content with the second method and could obtain only a very broad survey of the ion-spectrum.

The apparatuses made use of are described in full detail. Interesting is the use of an electrometer-triode for the registering of the number of ions collected.

A number of preparative measurements is necessary, concerning those of the capacities C_R and C_A and the volume V, the determination of the maximum mobility and measurements of the leak. The leak-stream depends upon the voltage W applied and upon the hour of the day, showing a minimum at 4^h, a maximum at about 11^h. The cause must be due to the variable amount of emanation in the atmosphere, ionizing through the wall of the vessel the stationary air in the aspirator. It should be possible therefore to diminish the leak by means of an absorbing lead screen.

The new ionization-balance has been tested by measurements at sea during Clay's cosmic-ray expedition in 1933. The mean result, $q=2.0J$, is larger than the ionization due to cosmic rays only, being $1.60J$ according to measurements of Clay and Jongen. The *Carnegie* measurements have shown that the emanation is increased considerably by land-effects, up to $0.6J$ even at 400 km off the coast of South America, whereas the part due to the emanation of the air above the ocean is only $0.25J$. Therefore the difference found may be ascribed to the neighborhood of the coast during Clay's expedition.

The author discusses the diverging results of different investigators and concludes that the divergencies are to be attributed to differences in the limiting mobilities. He shows that the diurnal variations for limiting mobilities varying from 0.35 (J. Clay) up to 7.0 (A. J. Leckie) agree, showing maxima at 3^h and at 12^h-14^h, minima at 7^h and about 20^h. Simultaneous observations with different limiting mobilities are urgently wanted.

To conclude we may mention some researches on the influence of rain and fog. During heavy rain the number of fast ions is increased to tenfold the normal value, especially by the formation of Lenard ions (waterfall-ionization); the influence of fog is in decreasing of the mobility of the fast ions.

A summary in English (pages 114-118) and a list of literature conclude the paper.

S. W. VISSER

RADIO FADE-OUTS AT HUANCAYO AND WATHEROO MAGNETIC OBSERVATORIES, FEBRUARY 1937 THROUGH JUNE 1938

By S. L. Seaton

Automatic vertical-incidence recording of ionospheric heights has been continued at the Watheroo Magnetic Observatory, Western Australia, and at the Huancayo Magnetic Observatory, Peru, of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, from the date of the last report [see 1 of "References" at end of paper] through October 1937 for Huancayo and through April 1938 for Watheroo using a fixed frequency of 4.8 mc/sec. These records have been examined and all radio fade-outs are listed in Tables 1 and 2.

From November 1937 and from May 1938 at Huancayo and Watheroo, respectively, fade-outs were recorded by means of automatic multifrequency equipments recently installed [2] which replace the 4.8 mc/sec fixed-frequency recording. Records are incomplete during November and December 1937 from Huancayo and during April and May 1938 from Watheroo because of installation and adjustment of the new equipments.

Table 3 shows total minutes of fade-out each month for the scale of intensity suggested by Berkner and Wells [1]. That scale is as follows: More pronounced, 3; moderate, 2; slight, 1; slight diminution of echo-strength, just recognizable on the record but nevertheless noticeable in wave-propagation over long distances, 1/2. The data of Table 3 are shown graphically in Figure 1.

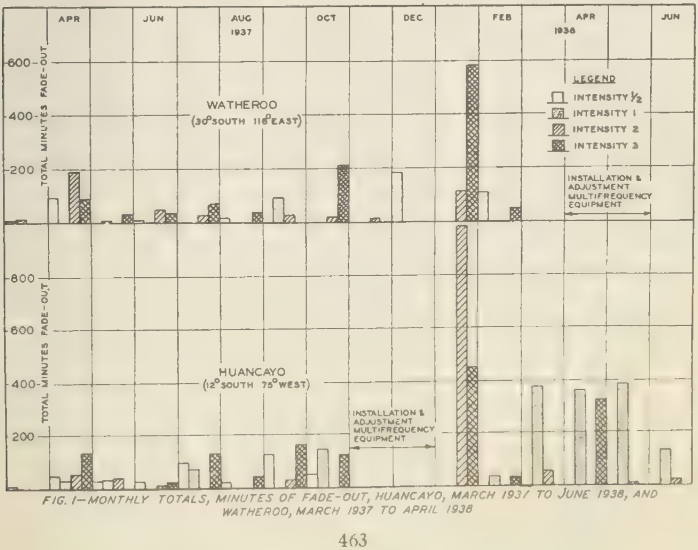


FIG. 1—MONTHLY TOTALS, MINUTES OF FADE-OUT, HUANCAYO, MARCH 1937 TO JUNE 1938, AND WATHEROO, MARCH 1937 TO APRIL 1938

From February 1937 through April 1938 a total of 73 fade-outs were recorded at Watheroo and a total of 116 at Huancayo from March 1937 through June 1938. Of the 73 identified at Watheroo nine were intensity 1/2, while of the 116 at Huancayo 33 were intensity 1/2. It is to be noted that the *E*-region at Huancayo is more consistent in its presence and behavior than at Watheroo. For this reason the detection of fade-outs of intensity 1/2 is reliable at Huancayo but uncertain at Watheroo—a natural condition favoring the identification of many more fade-outs of intensity 1/2 at Huancayo than at Watheroo. This is especially true throughout the period when 4.8 mc/sec fixed-frequency recording was used.

Table 1—*Radio fade-outs recorded at the Watheroo Magnetic Observatory on 4.8 mc/sec*

Date	GMT Begin	GMT End	Intensity	Date	GMT Begin	GMT End	Intensity	Date	GMT Begin	GMT End
	h m	h m			h m	h m			h m	h m
1937				*1937*				*1937*		
Feb. 26	01 38	01 56	1	June 23	10 29	10 31	3	Oct. 1	03 46	05 50
26	02 30	uncertain	1	23	10 59	11 00	2	5	22 57	23 00
27	04 27	04 57	1/2	23	11 15	11 23	2	6	00 21	00 25
28	04 23	04 31	1	30	08 50	09 12	2	6	05 03	05 16
28	04 57	05 15	1	30	09 32	09 44	2	7	01 40	01 44
28	05 27	05 29	1	July 4	04 56	05 04	2	7	02 24	03 10
28	07 50	08 30	1/2	4	08 47	09 08	2	8	05 14	05 26
Mar. 1	09 40	09 41	1/2	24	06 30	06 31	3	8	05 26	05 35
24	03 28	03 30	1	24	06 40	06 41	3	Nov. 16	03 04	03 14
Apr. 22	03 30	05 05	1/2	24	11 53	12 01	3	Dec. 16	04 50	07 50
23	03 05	uncertain	1	27	03 25	03 30	3	*1938*		
24	02 44	04 32	2	27	06 02	06 26	3	Jan. 16	00 44	02 41
24	10 45	11 28	2	28	06 15	07 01	3	17	03 06	03 14
25	01 00	01 12	3	Aug. 10	09 43	09 50	1/2	17	05 18	05 26
25	05 55	06 20	3	10	10 28	10 36	1/2	21	01 32	02 05
25	07 30	08 05	3	30	02 30	03 00	3	23	02 34	02 50
25	08 35	08 41	3	Sep. 5	02 28	02 30	1	23	03 25	03 55
25	09 58	10 37	2	8	03 35	03 36	2	23	04 17	05 40
May 4	06 20	06 22	3	12	03 25	04 28	1	23	07 10	07 36
10	03 15	03 31	3	12	05 03	05 10	2	24	02 44	07 51
15	08 56	08 59	1	12	05 10	05 34	1	26	00 40	02 45
25	01 55	02 06	3	12	06 05	06 13	2	Feb. 2	05 45	05 51
June 3	06 07	06 31	3	12	06 20	06 27	2	6	04 05	04 37
13	04 16	04 27	3	30	03 15	03 18	2	11	06 12	06 24
15	05 55	05 57	3	30	05 13	05 16	2	20	04 15	06 02
22	10 55	11 00	1/2					Mar.	No	ne

TABLE 2—*Radio fade-outs recorded at the Huancayo Magnetic Observatory on 4.8 mc/sec through October 1937, and multifrequency thereafter*

ate	GMT				In-ten-sity
	Begin		End		
937	h	m	h	m	
r. 1	19	05	19	07	1/2
r. 1	17	26	17	31	1/2
18	13	05	13	22	1/2
21	14	53	15	14	3
22	18	00	18	12	1/2
22	18	51	19	42	3
24	20	04	20	10	1/2
25	13	53	14	02	1/2
25	15	51	16	00	2
25	16	52	17	35	3
25	19	56	20	05	1
25	20	50	21	28	2
25	21	28	21	32	3
25	21	32	21	44	2
26	16	[a]	17	[a]	3
27	15	50	16	00	1
27	16	46	16	58	3
27	18	25	18	31	1
27	21	02	21	10	1
29	21	13	21	20	3
ay 1	20	31	20	40	2
2	15	53	16	02	2
5	16	[a]	16	53	2
9	13	50	14	22	1
17	18	[a]	19	03	2
19	16	15	16	20	2
23	21	28	21	35	1/2
25	13	28	13	43	1/2
25	16	55	17	13	3
27	20	59	21	08	1/2
ne 2	19	14	19	20	1/2
9	14	21	14	35	1/2
17	20	28	20	35	1/2
22	14	07	14	10	1/2
24	13	13	13	34	3
24	17	42	18	00	2
24	18	36	18	44	3
ly 1	14	15	14	40	1/2
6	13	44	13	47	1/2
6	15	10	15	22	1/2
7	18	47	18	55	3

Date	GMT				In-ten-sity
	Begin		End		
1937	h	m	h	m	
July 8	17	29	17	40	1
9	16	30	16	45	1/2
10	16	35	[a]		1/2
11	19	16	19	36	3
12	18	15	18	30	1/2
13	17	59	18	01	1/2
14	16	45	17	00	1
18	18	40	19	00	1/2
20	19	46	20	10	1
22	18	05	16	30	1
23	19	41	19	49	1/2
26	16	34	[a]		3
29	15	38	15	44	3
31	16	20	18	05	3
Aug. 2	14	58	15	10	1/2
7	14	10	14	25	3
13	13	12	13	28	1/2
28	19	28	19	57	3
Sep. 11	14	30	14	38	1/2
21	18	20	18	27	1/2
30	16	03	17	25	3
30	17	25	18	44	1/2
30	18	44	19	05	3
30	19	05	19	37	1/2
30	19	37	20	05	2
30	20	35	20	42	1/2
Oct. 2	16	54	17	15	3
4	20	47	21	27	3
5	17	04	17	51	3
5	20	40	20	46	1/2
7	13	32	13	47	1/2
7	15	30	15	45	3
7	20	45	21	10	1
8	16	35	[a]		3
9	15	18	16	25	1
11	15	25	16	11	1
11	16	23	16	27	1
11	19	56	19	58	1
16	18	45	19	03	1/2
28	17	31	17	40	1/2
28	18	26	18	35	1/2

Date	GMT				In-ten-sity
	Begin		End		
1938	h	m	h	m	
Jan. 13[b]	13	53	17	00	3
14	14	30	19	00	2
15	17	00	17	30	2
15	18	50	19	30	2
15	20	00	20	30	2
16	16	30	20	50	2
17	16	20	21	15	2
20	17	55	22	25	3
26	20	20	21	15	2
Feb. 3	17	30	18	15	3
20	13	00	13	45	1
Mar. 5	16	30	17	20	1
5	18	20	19	20	1
15	14	00	14	30	2
16	21	45	22	15	1
20	12	00	13	30	1
23	15	00	15	40	1
23	17	40	18	15	1
24	16	00	16	30	2
29	18	45	20	00	1
Apr. 4	21	40	22	30	1
6	15	45	17	00	1
7	12	30	16	30	3
22	16	00	19	00	1
23	14	00	15	00	1
23	19	30	21	00	3
May 9	16	50	18	00	1
11	15	10	15	30	2
12	17	00	17	30	1
17	12	00	13	40	1
19	19	50	20	40	1
24	16	00	16	20	1
24	17	35	18	50	1
27	18	00	[a]		2
28	16	30	16	40	1
29	18	40	19	15	1
June 6	15	20	16	10	1
8	15	00	16	00	1
8	17	30	18	00	1
29	15	00	15	15	2
30	15	00	15	15	2

[a]Uncertain.
[b]Values from January 13, 1938, as tabulated by staff at Huancayo

TABLE 3—*Monthly total minutes of fade-out of various intensities, Watheroo and Huancayo*

Month	Watheroo intensity				Huancayo intensity			
	1/2	1	2	3	1/2	1	2	3
1937								
Mar.	1	2	...	...	2	...	...	...
Apr.	95	...	190	78	49	33	59	138
May	...	3	...	29	31	32	41	...
June	5	...	43	39	30	...	18	29
July	...	...	29	75	100	75	...	139
Aug.	15	...	...	30	26	...	...	44
Sep.	...	89	29	...	133	...	38	163
Oct.	...	...	9	216	57	144	...	123
Nov.	...	...	10	...	...	...	...	...
Dec.	180	...	...	...	...	...	...	...
1938								
Jan.	...	...	113	580	...	...	980	457
Feb.	107	...	...	50	...	45	...	45
Mar.	...	...	...	...	...	380	60	...
Apr.	...	...	...	...	...	365	...	330
May					...	390	20	...
June					...	140	30	...

Of all the months represented in Figure 1, January is outstanding for total minutes of fade-out and for intensity at both stations.

References

[1] L. V. Berkner and H. W. Wells, Terr. Mag., **42**, 183-194 (1937).

[2] L. V. Berkner, H. W. Wells, and S. L. Seaton, Trans. Edin. Meeting, Part V, B. Iono.-Cos. Rad., 340-357 (1936).

DEPARTMENT OF TERRESTRIAL MAGNETISM,
CARNEGIE INSTITUTION OF WASHINGTON,
Washington, D. C., August 10, 1938

THE IONOSPHERE AT HUANCAYO, PERU, APRIL, MAY, AND JUNE, 1938

By H. W. Wells and H. E. Stanton

This report on ionospheric conditions is in continuation of those published in preceding issues of this Journal (**43**, 169-171, 257-260, 1938) submitting results of continuous multifrequency ionospheric recordings at the Huancayo Magnetic Observatory. The current data for the months, April, May, and June, 1938, are obtained from recordings for each hour of the day and for every day of the month except for short intervals necessary for maintenance to the equipment.

Table 1 contains mean hourly values of virtual height, critical frequency, and lowest frequency received for the second quarter of 1938. Figure 1 presents the data of Table 1 in graphical form. The following general discussion of characteristics seems pertinent:

(1) *F-region*—Virtual heights for May were generally greater than for April except for the post-sunset "hump" in the early evening which is generally associated with the greatest heights of the day. Likewise, heights for June were generally greater than for May except during the same hours of the early evening. It follows that the total range in heights was smaller for May than for April, and the range for June was less than that for May. The tendency during daytime was to greater heights during this period but with less-pronounced "humps" in the early evening.

F-region critical frequencies show a decreasing trend during the entire period. This is apparently a continuation of the decreasing trend which has been effective since February, 1938. The overall range in f°_{F} likewise exhibits a decreasing trend during the period, the range for May being less than for April, and range for June being less than for May.

(2) F_1-*region*—Virtual heights show a general tendency to lower values during the entire period with less difference, however, between values in May and June than between those in April and May.

Likewise, the F_1-region critical frequencies reveal a trend to lower values through May but those in June are found to be somewhat greater than those for May. The critical frequencies in this region continue to be poorly defined and occasions are seldom, even at midday, when the individual wave-components are distinguishable in transition from F_1- to F_2-region.

(3) *E-region*—No significant change or tendency in heights seems apparent during the period. *E*-region critical frequencies, however, show a consistent tendency to lower values during the entire period as would be expected on the basis of ionization by ultraviolet radiation for this sub-equatorial location.

(4) *Lowest frequency received*—Examination of f_{min} also indicates a decreasing trend for the period. The effect could be interpreted as a result of decreased absorption in the lower ionosphere. However, the reality of this effect may be questioned, especially for June, since adjust-

Table 1—*Mean hourly values of ionospheric data, Huancayo Magnetic Observatory, April, May, and June, 1938*

EST	h_E	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$	f_{min}
				April, 1938			
h	km	km	km	mc/sec	mc/sec	mc/sec	mc/sec
00	100		219	1.35		9.69	0.96
01	99		222	1.19		8.58	1.01
02	99		232	1.11		7.47	1.02
03	100		232	1.01		6.46	0.89
04	100		248	1.04		5.69	0.96
05	100		250	1.02		4.68	0.96
06	100		267	1.76		5.92	1.18
07	108		248	2.92		9.71	1.59
08	107	238	254	3.64	4.79	11.66	2.58
09	105	229	268	3.99	5.08	12.19	2.96
10	105	225	263	4.27	5.45	11.75	3.28
11	106	224	281	4.43	5.56	11.53	3.58
12	106	225	280	4.52	5.56	11.38	3.60
13	105	220	280	4.41	5.47	11.51	3.51
14	106	219	278	4.26	5.34	11.59	3.18
15	108	226	266	3.87	4.94	12.26	2.87
16	109	230	250	3.38	4.43	11.77	2.21
17	111		264	2.68		11.15	1.40
18	107		314	1.36		10.82	0.97
19	99		377	1.03		9.77	0.95
20	104		343	1.11		9.77	0.92
21	103		285	1.19		9.84	0.87
22	100		240	1.26		10.06	1.02
23	100		226	1.35		9.85	0.99

EST	h_E	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$	f_{min}
				May, 1938			
h	km	km	km	mc/sec	mc/sec	mc/sec	mc/sec
00	98		220	1.10		7.74	1.05
01	97		226	1.00		7.23	0.96
02	100		231	0.93		6.66	0.91
03	100		242	0.91		5.73	0.90
04	105		251	0.93		5.12	0.89
05	100		253	0.96		4.71	0.92
06	116		272	1.59		5.71	1.23
07	107	240	248	2.84	4.63	8.78	1.52
08	109	234	262	3.52	4.79	10.71	2.41
09	106	224	273	3.85	5.23	11.33	2.86
10	106	219	282	4.09	5.39	11.23	3.11
11	105	216	289	4.28	5.45	10.73	3.21
12	104	214	292	4.20	5.45	10.49	3.38
13	105	213	293	4.20	5.39	10.31	3.22
14	104	214	288	4.04	5.24	10.34	2.88
15	105	228	272	3.72	4.79	10.37	2.76
16	109	235	256	3.31	4.18	10.23	1.88
17	109		268	2.45		9.98	1.34
18	118		324	1.19		9.28	1.16
19	96		352	1.09		8.46	0.99
20	104		307	1.39		8.78	1.12
21	95		261	1.34		8.70	1.22
22	95		234	1.37		8.11	1.29
23	97		226	1.25		7.98	1.16

EST	h_E	h_{F_1}	h_{F_2}	f°_E	$f^\circ_{F_1}$	$f^\circ_{F_2}$	f_{min}
				June, 1938			
h	km	km	km	mc/sec	mc/sec	mc/sec	mc/sec
00	97		223	0.95		7.26	0.84
01	103		229	0.90		6.90	0.81
02	93		228	0.84		6.46	0.80
03	97		235	0.80		5.45	0.77
04	100		240	0.84		4.67	0.82
05	105		249	0.89		4.12	0.85
06	105		283	1.36		4.68	0.92
07	102		249	2.50		7.15	1.06
08	105	227	274	3.14	4.85	8.92	1.50
09	102	218	294	3.60	5.29	9.35	1.96
10	102	213	315	3.84	5.42	9.36	2.32
11	102	207	320	4.07	5.46	9.29	2.48
12	103	208	325	4.12	5.45	9.27	2.58
13	103	205	324	3.97	5.43	9.34	2.47
14	102	206	324	3.72	5.33	9.39	2.28
15	103	214	310	3.46	5.06	9.47	1.79
16	104	225	280	2.98	4.54	9.48	1.39
17	103		255	2.24		9.33	1.04
18	104		296	1.06		8.86	0.88
19	105		314	1.05		8.21	0.82
20	100		289	1.06		8.21	0.87
21	97		257	1.19		8.10	0.94
22	99		235	1.08		7.72	0.91
23	97		228	1.02		7.68	0.90

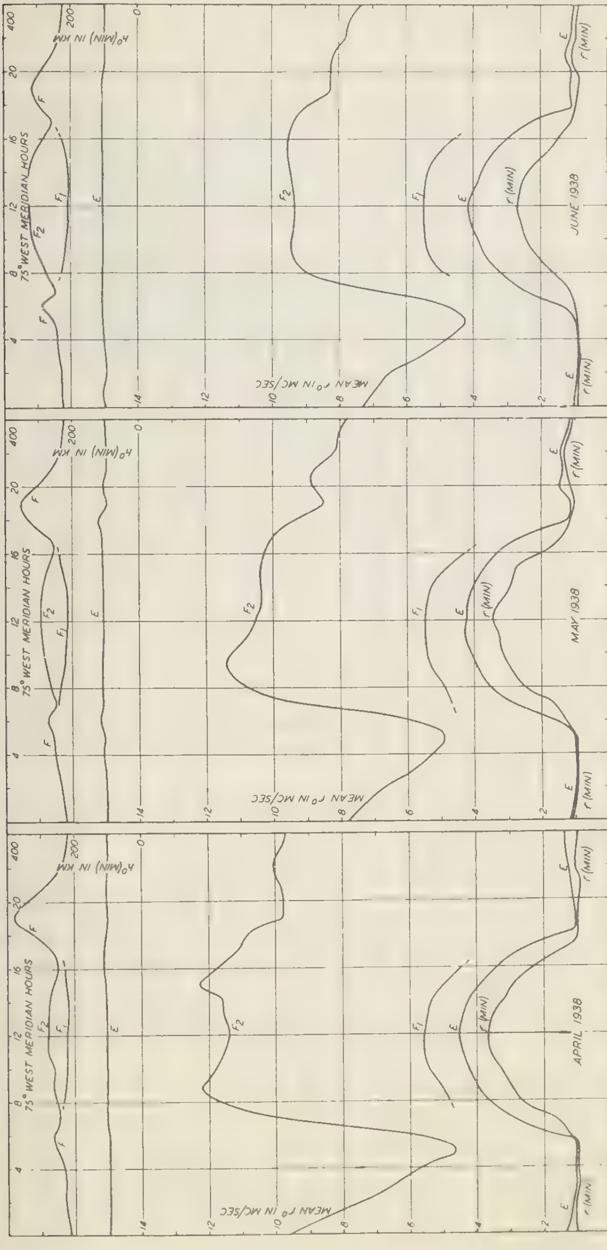


FIG 1—MEAN CRITICAL FREQUENCY (f^0), MINIMUM VIRTUAL HEIGHT (h^0-MIN), FOR IONOSPHERIC REGIONS, APRIL, MAY, AND JUNE, 1938, HUANCAYO, PERU

TABLE 2—*Root-mean-square values of frequencies, Huancayo Magnetic Observatory, April, May, and June, 1938*

EST	$f°_E$	$f°_{F_1}$	$f°_{F_2}$	f_{min}	$f°_E$	$f°_{F_1}$	$f°_{F_2}$	f_{min}	$f°_E$	$f°_{F_1}$	$f°_{F_2}$	f_{min}
	April, 1938				*May, 1938*				*June, 1938*			
h	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*	*mc/sec*
00	1.37		9.76	0.99	1.13		7.79	1.08	1.00		7.30	0.87
01	1.21		8.68	1.03	1.04		7.28	0.99	0.94		6.96	0.83
02	1.12		7.57	1.12	0.96		6.74	0.94	0.87		6.53	0.82
03	1.03		6.63	0.91	0.93		5.85	0.92	0.83		5.56	0.79
04	1.06		5.92	0.98	0.95		5.26	0.91	0.87		4.80	0.85
05	1.03		4.99	0.98	0.99		4.91	0.95	0.92		4.27	0.89
06	1.76		6.00	1.24	1.60		5.80	1.26	1.36		4.74	0.95
07	2.93		9.73	1.68	2.85	4.66	8.83	1.60	2.52		7.18	1.11
08	3.65	4.80	11.68	2.68	3.52	4.87	10.76	2.50	3.17	4.86	8.94	1.60
09	3.99	5.09	12.21	3.00	3.85	5.25	11.37	2.87	3.61	5.29	9.39	2.06
10	4.27	5.45	11.79	3.31	4.09	5.40	11.28	3.16	3.84	5.42	9.41	2.41
11	4.43	5.56	11.58	3.61	4.28	5.47	10.79	3.24	4.08	5.46	9.32	2.56
12	4.53	5.56	11.41	3.62	4.21	5.47	10.53	3.43	4.13	5.45	9.31	2.68
13	4.42	5.47	11.54	3.54	4.20	5.41	10.36	3.25	3.97	5.43	9.37	2.58
14	4.26	5.34	11.63	3.20	4.04	5.29	10.38	2.92	3.73	5.33	9.42	2.38
15	3.87	4.95	12.31	2.88	3.72	4.87	10.40	2.79	3.47	5.07	9.51	1.88
16	3.39	4.44	11.79	2.25	3.31	4.24	10.26	1.93	2.99	4.55	9.50	1.47
17	2.68		11.18	1.43	2.46		10.00	1.35	2.26		9.35	1.07
18	1.37		10.86	0.98	1.19		9.31	1.17	1.06		8.88	0.91
19	1.09		9.81	1.01	1.13		8.50	1.01	1.11		8.24	0.85
20	1.13		9.85	0.94	1.44		8.82	1.15	1.09		8.24	0.91
21	1.22		9.92	0.90	1.36		8.76	1.25	1.26		8.16	1.06
22	1.30		10.16	1.06	1.42		8.16	1.33	1.10		7.79	0.95
23	1.39		9.93	1.04	1.29		8.05	1.18	1.07		7.70	0.94

ments to the equipment resulted in increased transmitter-output and receiver-sensitivity, both of which extend recordings to lower frequencies. Accordingly, rigid interpretation seems inadvisable until a more extended series of data are available.

Table 2 gives root-mean-square values of frequencies for the same period. Since ionization is proportional to the square of frequency these values are more representative of *average ionization* than the normally-used means of critical frequencies. The difference between the root-mean-square values of Table 2 and the arithmetical-mean values of Table 1 is an approximate indication of the scatter in the individual observations. Thus for the E- and F_1-regions where the day-to-day values for a certain hour have little variation there may be no difference between the two Tables; while for the F-region where frequencies are found to vary appreciably, the difference may be of the order of a few per cent with the root-mean-square values always greater, of course.

HUANCAYO MAGNETIC OBSERVATORY,
Huancayo, Peru, August 16, 1938

THE MAGNETIC CHARACTER OF THE YEAR 1937 AND THE NUMERICAL MAGNETIC CHARACTER OF DAYS 1937

By G. van Dijk

The annual review of the "Caractère magnétique de chaque jour" for 1937 has been drawn up in the same manner as for the preceding years.[1] Sixty-two observatories contributed to the quarterly tables; fifty-six of them sent complete data.

Table 1 (reproduced from Table II of the annual review) contains the mean character of each day for each month. The lists of calm days and disturbed days, and the days recommended for reproduction are also reprinted here as Table 2.

[1]Terr. Mag., **33**, 203 (1928); **34**, 207 (1929); **35**, 178 (1930), **36**, 255 (1931); **37**, 259 (1932); **38**, 301-302 (1933); **39**, 237-238 (1934); **40**, 383-384 (1935); **41**, 351-352 (1936); **42**, 395-396 (1937).

TABLE 1—*Mean magnetic character-numbers for each day of 1937 from data supplied by 56 observatories*

Month	Dates														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1937															
January....	0.1	0.7	0.6	0.4	0.2	0.1	1.6	0.6	1.2	1.4	1.0	0.9	0.6	0.2	0.1
February...	0.6	0.7	1.9	1.2	1.2	1.1	0.6	0.4	1.6	1.2	1.0	1.1	1.1	1.0	0.9
March.....	1.5	1.3	0.1	0.4	1.8	0.6	0.1	0.0	0.4	0.4	0.1	0.1	1.0	1.3	1.6
April	0.5	1.4	1.2	0.7	0.3	0.4	0.4	0.1	0.1	0.1	0.7	1.5	0.8	0.1	0.4
May.......	1.0	0.4	0.6	1.3	1.9	0.1	0.1	0.3	1.1	0.9	0.9	0.3	0.4	0.9	0.6
June.......	0.6	0.6	0.3	0.7	1.3	1.6	0.8	0.6	0.3	0.9	0.4	0.1	1.3	0.7	0.6
July.......	0.7	0.6	0.3	0.3	0.9	1.2	1.1	0.2	1.1	0.9	1.0	0.7	0.4	1.5	0.8
August.....	0.7	1.8	1.2	1.5	0.5	0.7	0.5	0.2	0.2	0.2	0.3	0.2	0.1	0.4	0.7
September..	0.9	0.2	0.1	0.5	0.6	0.5	0.4	0.4	0.4	1.3	1.5	0.2	0.9	0.9	0.6
October....	1.4	0.5	1.4	1.9	0.6	0.8	1.2	1.6	1.9	1.6	1.7	1.5	0.9	0.7	1.2
November..	0.3	0.7	0.2	0.1	0.1	0.1	0.9	1.1	1.0	0.3	1.0	0.8	0.4	0.1	0.0
December..	1.1	0.7	0.3	0.1	0.3	0.6	1.0	0.8	0.5	0.8	0.7	0.2	0.1	0.1	0.2

Month	Dates																Means
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
1937																	
January....	0.1	0.2	0.2	0.2	0.7	1.1	0.3	0.1	0.2	0.0	0.2	1.3	1.0	0.7	1.1	0.2	0.55
February....	0.8	0.7	1.0	1.6	1.0	1.1	0.8	0.2	0.4	0.6	0.3	0.5	0.6				0.89
March......	0.7	0.8	0.5	0.3	0.2	0.5	1.5	0.9	0.7	0.4	0.9	1.7	1.2	0.6	0.7	1.9	0.78
April........	0.1	0.4	0.8	0.9	0.5	0.8	0.4	0.5	1.8	2.0	2.0	1.8	2.0	1.2	1.2		0.83
May........	0.8	0.3	0.3	0.6	0.1	0.7	0.7	0.3	0.5	1.2	1.0	1.3	1.7	1.4	0.7	0.6	0.74
June........	0.8	1.0	0.6	0.2	1.3	0.8	1.2	0.4	0.9	0.7	0.2	1.6	0.9	0.4	0.3		0.74
July........	0.5	0.4	0.5	1.5	1.3	0.8	1.5	1.2	1.5	1.2	0.7	0.2	0.2	0.1	0.6	0.4	0.78
August......	0.1	0.2	0.2	0.4	0.2	0.4	1.9	0.3	0.0	0.1	0.4	1.1	0.9	0.5	0.1	0.1	0.53
September...	0.8	0.6	0.9	0.5	0.2	0.6	0.5	0.7	0.8	0.2	0.6	0.5	0.3	0.1	1.7		0.61
October.....	0.5	0.1	0.2	0.3	0.0	0.5	1.0	1.6	1.6	1.1	1.4	1.2	1.0	0.4	0.2	0.3	0.98
November...	0.0	0.5	1.5	1.5	1.2	0.8	1.4	1.4	1.2	0.4	0.3	0.6	1.1	1.6	1.5		0.73
December...	0.1	0.1	1.6	1.5	1.2	0.5	0.7	1.7	1.3	0.7	0.9	0.1	0.1	0.2	0.2	1.0	0.63

TABLE 2—*Dates of five magnetically calm and five disturbed days with mean character-numbers during 19*

Month	Calm days						Disturbed days				
1937											
January.....	(0.07)	**1,**	**15,**	**16,**	**23,**	**25**	**7** (1.6),	**9** (1.2),	**10** (1.4),	**27** (1.3),	**30**
February....	(0.35)	**8,**	**23,**	**24,**	**26,**	**27**	**3** (1.9),	**5** (1.2),	**9** (1.6),	**19** (1.6),	**21**
March......	(0.08)	**3,**	**7,**	**8,**	**11,**	**12**	**1** (1.5),	**5** (1.8),	**15** (1.6),	**27** (1.7),	**31**
April........	(0.10)	**8,**	**9,**	**10,**	**14,**	**16**	**24** (1.8),	**25** (2.0),	**26** (2.0),	**27** (1.8),	**28**
May........	(0.16)	**6,**	**7,**	**18,**	**20,**	**23**	**4** (1.3),	**5** (1.9),	**27** (1.3),	**28** (1.7),	**29**
June........	(0.24)	**9,**	**11,**	**12,**	**19,**	**26**	**5** (1.3),	**6** (1.6),	**13** (1.3),	**20** (1.3),	**27**
July........	(0.22)	**3,**	**8,**	**27,**	**28,**	**29**	**14** (1.5),	**19** (1.5),	**20** (1.3),	**22** (1.5),	**24**
August......	(0.09)	**13,**	**16,**	**24,**	**25,**	**30**	**2** (1.8),	**3** (1.2),	**4** (1.5),	**22** (1.9),	**27**
September...	(0.17)	**3,**	**12,**	**25,**	**28,**	**29**	**1** (0.9),	**10** (1.3),	**11** (1.5),	**14** (0.9),	**30**
October.....	(0.19)	**17,**	**18,**	**20,**	**29,**	**30**	**4** (1.9),	**8** (1.6),	**9** (1.9),	**10** (1.6),	**11**
November...	(0.04)	**4,**	**5,**	**6,**	**15,**	**16**	**18** (1.5),	**19** (1.5),	**23** (1.4),	**29** (1.6),	**30**
December...	(0.09)	**4,**	**13,**	**14,**	**27,**	**28**	**18** (1.6),	**19** (1.5),	**20** (1.2),	**23** (1.7),	**24**

Days recommended for reproduction
**April 24, April 26.
*February 3, March 31, April 28, May 5, August 22, September 30, October 9.

In the introduction a note has been inserted concerning the publication "Caractère magnétique numérique des jours" for 1937. Volumes XXII to XXV have been published along with the tables of "Caractère magnétique de chaque jour."

Forty-two observatories have sent lists for 1937; thirty-eight them were complete.

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THE CONSTRUCTION OF AN AZIMUTHAL EQUIDISTANT MAP CENTERED ABOUT THE GEOMAGNETIC NORTH POLE

By M. J. Pollak

Before describing the construction of the accompanying map it would be appropriate to make some explanatory remarks regarding its purpose, and the particular advantages of the azimuthal equidistant projection.

The map was constructed as an aid to the study of certain magnetic phenomena which take on additional significance when plotted on geomagnetic coordinates. A clear definition of this coordinate system is given by A. G. McNish:[1] "Many magnetic phenomena are frequently found to have a relatively simple distribution when consideration is given to the location of the observing stations relative to the pole of the first-degree harmonics of the Earth's general magnetic field. A coordinate system having this pole as its origin is called a system of geomagnetic coordinates." The northern geomagnetic pole, the one used as the center of projection of the map, is in latitude 78°.5 north and longitude 69°.0 west.

An azimuthal equidistant projection is one wherein all distances measured from the center of projection are proportional to the equivalent great-circle distances on the globe, and all plane angles at the center of projection equal their corresponding spherical angles. The true ratios of distances from the geomagnetic pole are of great value in a comparison of the observations from various stations. This property, together with the existence of true angles at the center, will bring out clearly any qualities of radial symmetry, in respect to the geomagnetic pole, which the observed phenomena may show.

In construction of the map a network of polar coordinates was drawn serving a twofold purpose, namely to supply the basic network on which the points of intersection of the geographic coordinates were plotted, and to constitute the geomagnetic coordinate system of the map. For both the geomagnetic and geographic coordinate systems only every tenth meridian and parallel was drawn. For the geomagnetic system this was a simple task as the meridians were diameters of the circular map and the parallels were evenly spaced concentric circles. The length of a degree of latitude was determined arbitrarily to fit the desired size of the map.

The next step in the construction was the computation of the geographic coordinate system. The polar coordinates, that is, the distance from the origin and the angle between the radius-vector and the prime direction, of any point on the map are each a function of the latitude and longitude of the corresponding point on the sphere and of the spherical coordinates of the new center of projection. The transforma-

[1] Terr. Mag., **41**, 37-43 (1936).

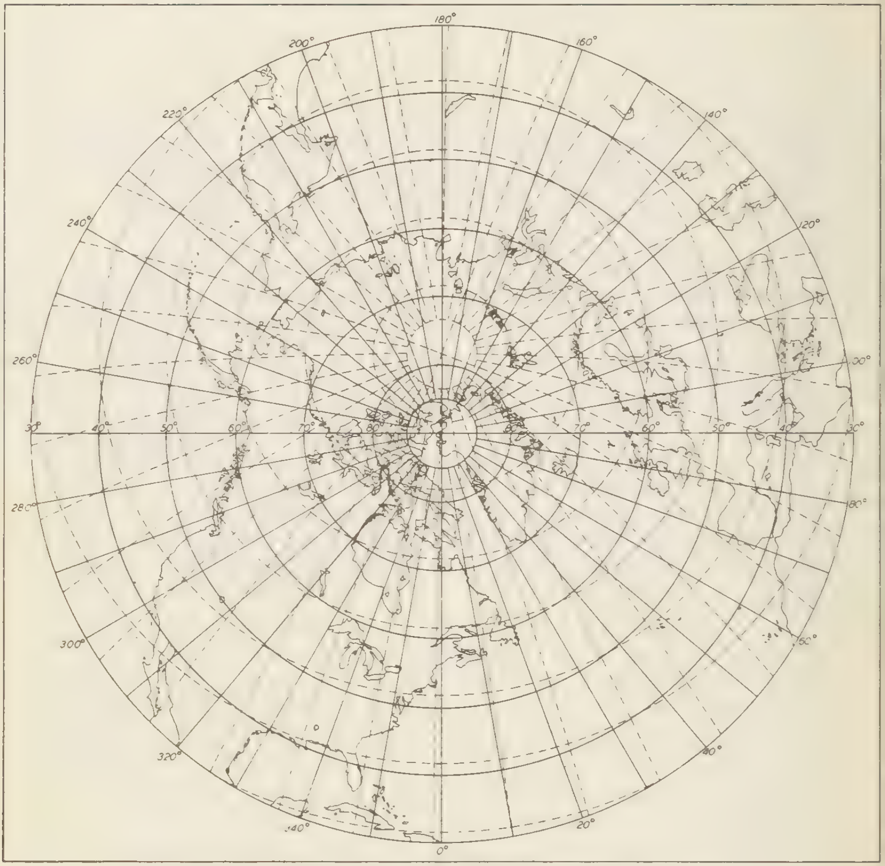

FIG 1—AZIMUTHAL EQUIDISTANT PROJECTION CENTERED ON GEOMAGNETIC NORTH POLE

tion of geographic to polar coordinates was carried out in two steps, namely, the change from geographic to geomagnetic coordinates, and then from geomagnetic to polar coordinates. However, in the first step less than half of the points had to be computed, due to the existence of a set of excellent nomographs.[1] The nature of these graphs is such that, given the geographic coordinates of a point, one can immediately read off its geomagnetic coordinates. The graphs have one shortcoming. Each one contains a set of curves which converge at the corners of the rectangular figure, thus making them worthless for certain regions of the globe. Hence the points in these regions were computed by means of the formulas

$$\cos \Theta = \sin \phi \sin \phi_0 + \cos \phi \cos \phi_0 \cos (\lambda - \lambda_0)$$
$$\cos \Lambda = (\sin \phi - \cos \Theta \sin \phi_0)/\cos\phi_0 \sqrt{1 - \cos^2 \Theta}$$

where, for a given point on the globe, Θ is the angular distance from the geomagnetic pole; Λ is the angle between the geomagnetic meridian and the meridian through the geographic and geomagnetic poles; (ϕ, λ) are the geographic latitude and longitude; and (ϕ_0, λ_0), are the geographic latitude and longitude of the geomagnetic pole. Then $(90° - \Theta)$ is the geomagnetic latitude and Λ is the geomagnetic longitude.

The transformation of geomagnetic coordinates on the sphere to polar coordinates on the map was extremely simple. The complement of the latitude, multiplied by the arbitrarily chosen length of one degree of latitude, gives the distance from the pole; the longitude equals the angle between the radius-vector and the prime direction. All that remained was the actual plotting of the points and the drawing of the connecting curves. Once the geographic coordinates have been drawn on the map, the geographic and hydrographic features need merely be copied from any available maps.

895 West End Ave., New York, New York.

(See also page 486)

PROVISIONAL SUNSPOT-NUMBERS FOR AUGUST TO OCTOBER, 1938

(Dependent alone on observation at Zürich Observatory and its station at Arosa)

Day	August	September	October
1	144[ddd]	106[d]	...
2	121	124[ad]	94
3	*EW*121[cc]	101[a]	55
4	153[d]	107	*M*...[ac]
5	132[dd]	120[b]	*M*106[acd]
6	133[a]	136	*M*102[c]
7	135[aaa]	100[a]	92
8	150[d]	88[a]	102
9	158	74	143[d]
10	161[ab]	56	152
11	173[ad]	67[d]	...[b]
12	132	59	134[b]
13	...	44	121
14	107[bd]	48	122
15	102	44[d]	103
16	*E*119[ac]	47[a]	78
17	106	46	*M* 71[c]
18	100	65	31[d]
19	104	55[d]	20
20	76	57	*E* 58[cd]
21	65[a]	56[ad]	55
22	72	70	46
23	*M* 94[acc]	86	*E* 61[c]
24	86	97[d]	...[a]
25	*E*113[cc]	*MM*131[acc]	91[aa]
26	103	150	104[ad]
27	91[d]	143[ab]	...
28	94[a]	137	*M*...[c]
29	114[d]	125[a]	148[ad]
30	105	131	...
31	...		155[a]
Means.....	116.0	89.0	93.5
No. days...	29	30	24

Mean for quarter, July to September, 1938: 123.3 (88 days)

Middle large bright chromospheric eruptions observed at GMT:
August 4, $8^{h}\ 34^{m}$ to $8^{h}\ 45^{m}$ and $9^{h}\ 00^{m}$ to $9^{h}\ 25^{m}$; August 14, $13^{h}\ 27^{m}$ to $14^{h}\ 10^{m}$.
September 18, $11^{h}\ 00^{m}$ to $11^{h}\ 15^{m}$, *W;* September 21, $6^{h}\ 56^{m}$ to $7^{h}\ 14^{m}$, *E;* September 22, $13^{h}\ 31^{m}$ to $13^{h}\ 50^{m}$, *E;* September 23, $15^{h}\ 45^{m}$ to $16^{h}\ 20^{m}$, *E;* September 25, $9^{h}\ 00^{m}$ to $9^{h}\ 15^{m}$, *E;* September 26, $8^{h}\ 43^{m}$ to $9^{h}\ 03^{m}$, *M.*
October 17, $9^{h}\ 43^{m}$ to $9^{h}\ 59^{m}$, *W.*

[a]Passage of an average-sized group through the central meridian.
[b]Passage of a large group or spot through the central meridian.
[c]New formation of a group developing into a middle-sized or large center of activity: *E*, on the eastern part of the Sun's disc; *W*, on the western part; *M*, in the central-circle zone.
[d]Entrance of a large or average-sized center of activity on the east limb.

Eidgen. Sternwerte,
Zürich, Switzerland

W. Brunner

THE BERNARD PRICE INSTITUTE OF GEOPHYSICAL RESEARCH

By B. F. J. Schonland

The University of the Witwatersrand, Johannesburg, provides higher education for the largest City in the Union of South Africa and, as a result of the considerable mining and industrial activities of the City, is well staffed and equipped on the scientific and engineering sides. The University has recently been able to establish a geophysical research laboratory through the generosity of the Carnegie Corporation of New York and of Dr. Bernard Price, a Director of the Victoria Falls and Transvaal Power Company. The Bernard Price Institute of Geophysical Research, as it is called, will be opened officially in October of this year.

There are a number of reasons why Johannesburg is a suitable center for the work of such an Institute. It is geographically and economically the center of white South Africa, which extends effectively from the Cape to the Zambesi River. It is the most industrialized City in Africa and has in consequence a number of academic and technical institutions in close proximity, together with excellent scientific libraries. The crust of the Earth has here been penetrated to a depth of 10,000 feet on an extensive scale as a result of mining operations, while the whole area of the Transvaal has been intensively studied by geologists and geophysical prospecting teams. It has exceptional interest in connection with atmospheric electricity in view of the heavy incidence of thunder-storms.

The Bernard Price Institute has been founded in the first place for the prosecution of pure scientific research in geophysics and as a secondary function to render such assistance in applied directions as may be desirable. Its relation to the University differs from that of other departments in that it is governed and its funds are administered by a separate Board of Control which is directly responsible to the Council of the University. The Director of the Institute is also Carnegie-Price Professor of Geophysics in the University, and as such does a strictly limited amount of post-graduate teaching and has a seat on the University Senate.

The permanent staff of the Institute consists of the Director, the Chief Assistant and the Mechanical Assistant in charge of the workshop. Other members of the staff are appointed on a temporary basis and at the present time there are five such additional members of the staff, of whom two are associates, members of the teaching staffs of other departments, whose research work is done in connection with the Institute.

The Laboratory, which was completed at the beginning of this year, is situated in the grounds of the University. Easy use can therefore be made of the facilities available in other departments and of the University library, while close contact can be maintained with other members of the staff and students.

Some of the investigations undertaken by the Institute will require quieter conditions than those prevailing on the present site and these will

be carried out on the University Research Farm in the country some eight miles away.

A plan of the two floors of the building is shown in Figure 1. Since it is anticipated that the Institute will grow considerably in the course of time, provision has been made to enable the top floor to be extended

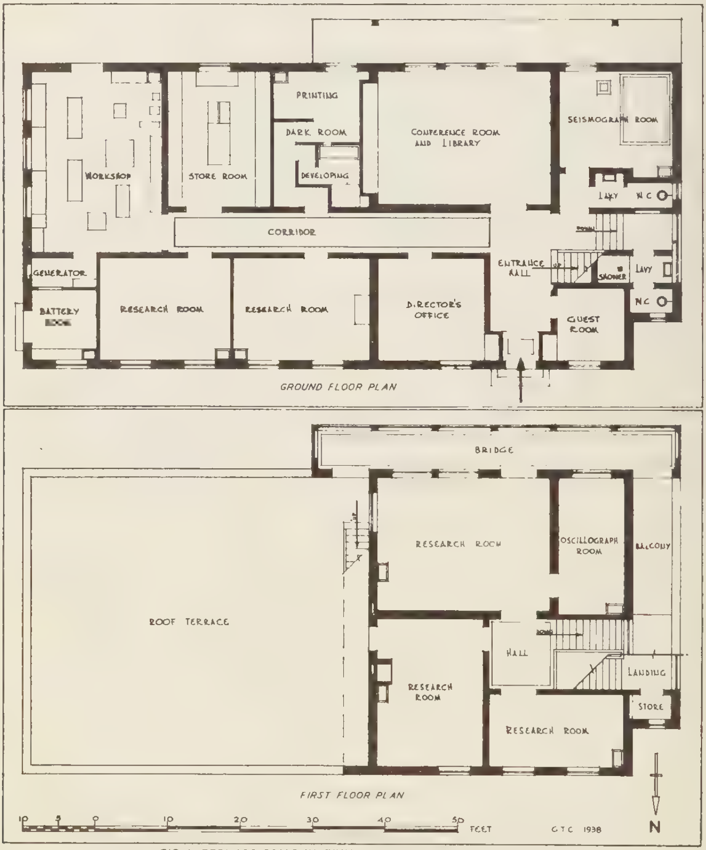

FIG. 1—BERNARD PRICE INSTITUTE OF GEOPHYSICAL RESEARCH

easily over the whole of the ground floor. At present it can accommodate some ten workers and this capacity could be doubled by the extension contemplated. The workshop and other service rooms are large enough for use in this enlarged laboratory without further alteration.

The following are the chief points in connection with the design of the building.

Ground floor

Conference-room—This also serves as the library and is fitted up for seminar meetings and lectures.

Workshop—All machines are unit driven, separate lathes, etc., being provided for the use of research workers.

Battery-room—A battery of chloride lead cells (250 ampere-hours, 50 volts) supplies each research room with two or more direct-current connections through a switchboard in the generator-room.

Dark-rooms—These are entered through a maze and ventilated by a staggered air-duct in the roof. The inner room, which is safe for panchromatic work, is used for developing and processing only. Enlargement and printing is done in the outer room.

Seismological room—This is placed on the southwest side of the building to be free from serious fluctuations in temperature. Part of the concrete floor and a non-magnetic concrete pillar are separated from the building by an air-space and go down to solid rock below.

Guest-room—The Institute serves as a central directing body for a number of research workers attached to University Institutions in other towns of the Union. To assist these men to spend some time with us during their vacations, a bedroom and a small bathroom are available. These facilities are also used for workers who have to spend the night in the laboratory. The guest-room is available for the use of overseas visitors to whom reference is made later.

First floor

The four rooms on this floor are designed primarily for use in investigations in the radio and atmospheric-electricity fields. These are provided with outlets of two-inch pipe to the roof and through the side-walls which make it easy to lead in wires from aerials and other conductors outside, while preserving high insulation. The largest room has a temporary wooden roof to enable it to be converted at some later date to a high-voltage laboratory.

Bridge

The lightning program of the Institute makes it necessary to provide facilities for photographing flashes in all directions with instruments which are electrically driven and controlled and which can be sheltered from rain. The glassed-in balcony shown on the south side of the building serves this purpose, being constructed in a manner similar to the navigating bridge of a ship. It provides a practically complete view all round and its glass windows can be opened out to act as rain-shields. The main view is to the south and the instruments employed are not affected by the lights of the town. Wiring from the bridge enables an observer to communicate by bell or telephone with any part of the building and to start and control the oscillographic equipment housed in the oscillograph-room.

Roofs

The roofs of the building are flat and constructed of concrete covered with thermally insulating material. Sockets are placed at each corner

which can take two-inch piping and thus serve to support the wireless masts required for various purposes. These masts act also as lightning conductors. The roofs are surrounded by parapets 2-1/2 feet high and bolts are provided at four-foot intervals along these to facilitate the rapid fixing of equipment outside.

General fittings

Every research room can be rendered completely light-tight by means of boxed blinds, the ventilators being staggered to exclude light. Vertical wooden battens extending from floor to ceiling and across the ceilings at four-foot intervals are provided for carrying wires and instruments. The floors are of Oregon pine to enable equipment to be screwed down. Electrical wiring between rooms, permanent or temporary, can be carried by numerous pipe-ducts through the walls.

Investigations and program

The present program of the Institute covers the fields of atmospheric electricity, seismology and crustal magnetization. The subjects being studied under these heads are as follows.

(1) *Atmospheric electricity* (*a*) Studies of the mode of development of the lightning discharge. These are being made both by the photographic method and by cathode-ray oscillography of the electrical field and its changes.

(*b*) Studies of the wave-form and characteristics of radio atmospherics from lightning discharges at great distances.

(*c*) Studies of the location, activity, and characteristics of thunderstorms in Southern Africa. These are being made by the method of radio-direction finding with automatic indication of bearing on a cathode-ray oscillograph, developed by Watson-Watt and others in England. The Institute station operates in conjunction with one in Durban and telephonic connection between the two stations has been provided by the Postmaster-General. The application of the results to meteorological forecasting and to aircraft warning is being examined.

(2) *Seismology*—(*a*) Studies of the Witwatersrand Earth-tremor which is of frequent occurrence and is due to the weakening of the Earth's crust as a result of mining operations. Instruments for the examination of its wave-form on a very open scale have been constructed. Other instruments which will be used in an attempt to localize the origin of the tremor by means of a seismological network are under construction.

(*b*) For general seismology a pair of horizontal seismographs of the Weichert type is installed as a preliminary to more elaborate studies in the field by means of which it is hoped to establish the thickness of the crustal layers of the sub-continent.

(3) *Crustal magnetism* Work is under way to examine experimentally the origins of the various magnetic anomalies associated with ferromagnetic shales and dykes on the Witwatersrand and elsewhere, some of which are reversed in sign.

It is the hope of those connected with the foundation of the Institute that as it progresses it may enter into the many other geophysical fields whose study in Africa may be of scientific value and that it may also act

as a central clearing house for geophysical studies in Southern Africa. In this connection it is of interest to note that a fund has been established to enable it to contribute towards the expenses of oversea workers who may wish to visit Africa and contact with whom will help to enlarge the scope of the Institute's activities.

Applied work—In return for financial support, all of which need not be used for applied purposes, the Institute is able to offer specialist assistance to industry in the form of consultation or of instrumental design and construction. Arrangements of this kind have been made with the Witwatersrand Chamber of Mines and with the Geological Survey of the Union and are contemplated with the radio organizations of the country. The support thus given has enabled the Institute to attach to its staff certain scientific specialists as associates.

The Bernard Price Institute of Geophysical Research,
Johannesburg, South Africa

REVIEWS AND ABSTRACTS

(See also page 462)

Année Polaire Internationale, 1932-1933: *Participation française*—Tome II; *Electricité atmosphérique, courants telluriques, actinométrie, radio-électricité, historique des missions.* Paris, Gauthier-Villars, 1938, 259 pp. 33 cm.

This is the second volume of results obtained by the French expeditions during the second International Polar Year, 1932-1933, issued by the French Commission for the Polar Year. The first volume, on terrestrial magnetism, the aurora, ozone, and cosmic rays, was reviewed previously (Terr. Mag., **41**, 286, 1936).

The first section of the present work deals with the atmospheric-electric observations made at Scoresby Sound in eastern Greenland (latitude 70° 29′.1 north, longitude 21° 57′.7 west). The program, described by A. Dauvillier, included measurements of potential-gradient, positive and negative conductivity, and the density and mobility of small ions in the atmosphere.

The potential-gradient was registered continuously at two separate stations from November 7, 1932, to August 10, 1933, using Benndorf recorders. Considerable difficulty attended the registration due to storms and drifting snow in the winter and frequent heavy fogs during the latter part of the time. Sufficient complete calm-day records for statistical study were lacking, so all the values obtained, both positive and negative, are tabulated and used in the means. The mean value of potential-gradient was found to be 71 volts per meter with maximum (95 v/m) in November and minimum (59 v/m) in April and May. Its diurnal variation, well-marked in winter, gave a simple curve with a maximum (105 v/m) at 18^h Greenwich time, and a minimum (72 v/m) at 2^h. The diurnal variation diminished to the point of disappearance in May, at the time when the field itself was smallest, and reappeared in July.

The conductivity due to small ions of both signs was measured twice each day using a Gerdien aspiration-apparatus with Wulf bifilar electrometers. From February 15 to August 30, the semi-daily eye-readings, made at noon and midnight, Greenwich time, were supplemented by continuous photographic registration. The mean value obtained for the total conductivity ($\lambda = 2.46 \times 10^{-4}$ sec^{-1}) is slightly lower than that observed over the oceans. The results also indicate a large disparity in the conductivities due to ions of the two signs ($\lambda_+ = 1.40 \times 10^{-4}$ sec^{-1}, $\lambda_- = 1.06 \times 10^{-4}$ sec^{-1}). The conductivity, very constant during the winter and spring, increased in the summer. The author concludes that the conductivity is practically all due to cosmic radiation during the winter and the increase in summer is caused by ionization arising from radioactive materials in the soil. The diurnal variation in conductivity was found, as usual, to be the inverse of that noted in the potential-gradient. Neither the potential-gradient nor the conductivity showed any variations which could be correlated with variations in auroral activity.

Measures of the density and mobility of small ions in the air were made on four occasions using an Ebert aspirator with Wulf bifilar electrometer. The mean ion-density was about 10^3 with a preponderance of positive ions, which showed a lower mobility than did the negative ions. The conductivities calculated from the ion-density measurements agreed well with those measured with the Gerdien apparatus on the same days.

The annual and diurnal variations of the air-earth current, as calculated from the records of potential-gradient and conductivity are also given. The mean value (1.7×10^{-16} ampere per cm^2) is unusually small for a land-station. Its diurnal-variation curve is similar to that of the conductivity and the curve of annual variation is a simple wave with a minimum at the spring equinox.

The bearing of these results on the general problem of the origin of the air-earth current is discussed by the author with the conclusion that it is of cosmic origin.

The second section, by J. P. Rothé, describes the earth-current work done at Scoresby Sound. Of the four lines planned originally to secure duplicate records, only two could be installed because of the difficulty in finding satisfactory electrode-sites. Both lines were about 700 meters long and were oriented nearly along the magnetic axes. The electrodes were copper coils set at depths between 1 and 1.5 meters. Photo-

graphic registration of the earth-potentials was carried on from November 15, 1932, to August 12, 1933, using D'Arsenval-type galvanometers with shunts to control the sensitivity. Calibration was effected by a substitution-method, a battery of known electromotive force and a large fixed resistance being substituted for the earthed lines. This set-up, since it included no large series-resistance, required an accurate knowledge of the line- and electrode-resistances, and of their time-variations, in order to evaluate the records. Frequent measurements showed that the electrode-resistances were high and variable during the winter. The soil-resistivity, measured with a "Megger" was high, ranging from 60,000 to 100,000 ohm-cm. During the spring and summer an attempt was made to determine the potential-difference between electrodes set in two small ponds about 1.5 km apart in a south-north direction using a recording milliammeter but the apparatus was not sensitive enough to give more than a record of large fluctuations during disturbances.

Because of the unfavorable conditions no satisfactory records were obtained during the winter. A total of 72 scalable grams were secured between March and July with fairly complete records only for April and May. Rothé attributes the difficulty in securing satisfactory records partly to variations in resistance and partly to wide variations in the earth-currents themselves during the course of the year. However, he entirely neglects any mention of contact-potentials. These electrochemical potentials always exist between any pair of earth-electrodes and make up a very large part of the recorded values. It can hardly be doubted that the wide variations in the recorded values arose from this source.

This same lack of consideration of contact-potentials leads Rothé to conclude the existence of a large unidirectional component of current-flow, nearly 0.5 volt per km, flowing a little south of magnetic west. At his north and east electrodes there was considerable alluvial soil, while the south and west electrodes were in solid rock. With such different environments it was only natural that there should have been a decided and consistently directed difference of potential between the two electrodes of a pair, but its existence does not indicate any actual current-flow. It is quite probable that all of the mean values of 300 mv recorded on the east-west line and of about 50 mv on the north-south line were due to this fact alone.

Rothé's study of the variations is much more satisfactory. In their general features the electrograms are very like those obtained at other Polar stations with frequent short-period fluctuations, the magnitude of which is large in comparison to the diurnal variation. In a superficial way the variations follow those in the magnetic elements, notably in H, but the short-period disturbances are markedly accentuated in the earth-currents as should be expected.

The diurnal variation, as determined in April and May and checked by incomplete records for March, June, and July, shows a decided maximum of current directed a little north of east at 6^h local time and a pronounced minimum (flow a little south of west) between 13^h and 15^h. The amplitude of the variation is five to ten times as great as that recorded at College-Fairbanks and Chesterfield. This may be due in part to high soil-resistivity and in part to the large sea areas adjacent to Scoresby Sound. The direction of current-flow as indicated by the diurnal hodogram is decidedly restricted to a line which is nearly at right angles to the magnetic meridian. The form of the hodogram is very like those obtained at Sodankylä and Harparanda. On the whole it appears that the results obtained at Scoresby Sound will fit fairly well into the picture of the general circulation of earth-currents as determined from the records at other stations and afford additional data for a more precise definition of it.

Section three summarizes the solar radition-measurements made at Tamanrasset and Bangui. The program at Tamanrasset (latitude 22° 41′ north, longitude 5° 38′ east, altitude 1315 meters), reported by M. Failletaz, consisted of continuous registration of the direct, total, reflected, and diffuse radiations, and direct determinations of the direct radiation over the entire spectrum and at specified wave-lengths. A Brillon and Leroux recorder was used. The Michelson apparatus used for the direct measurements was standardized monthly by means of an Ångstrom pyrheliometer. The measurements were made without a filter, with a yellow filter (λ, 526 mμ) and with a red filter (λ, 636 mμ).

Registration was attempted from January until September, 1933, but the first recorder was not sensitive enough and only a few records of direct radiation were secured until June 22, when a more sensitive recorder was put in service. From June 22 to September 10, fairly complete records were obtained for all four radiations although the sensitivity of the thermal-couples was too low to record accurately the reflected and diffuse radiation. Nine sample records from the one hundred complete

ones obtained are shown together with a chart giving the number of hours record obtained on each day of the period.

A typical summer-day record (July 13) shows the following features. The intensities are higher in the morning than in the afternoon for the direct, total, and diffuse radiations. The *D*-curve has a broad maximum between 9^h and 12^h with a mean value of 1.44 gr-cal/cm^2—min. After 9^h and until 16^h or 17^h, the *D*-curve shows numerous fluctuations on both sides of the mean the amplitude of which is often 0.1 gr-cal/cm^2—min. Integration of the curve gives a total of 884 gr-cal received during the day on each cm^2 of surface exposed normally to the rays. The total radiation curve is smoother with a sharper maximum between 11^h and 12^h. The values for reflected radiation are high with a very broad maximum between 9^h and 13^h. Only approximate values can be given for the diffuse radiation. On clear days it was about 0.25 gr-cal/cm^2—min and on cloudy days two or three times as great.

Direct determinations with the Michelson apparatus were made at 13^h from February to April, and at 8^h and 13^h from May to September. Detailed results of these measurements are given in a ten-page table. The maximum intensity of the direct radiation, reduced to a standard solar distance and a standard zenith-angle, and corrected for instrumental errors was 1.58 gr-cal/cm^2—min. This is somewhat higher than that observed at other stations of equal altitude.

The observations made at Bangui, in Equatorial Africa are reported by L. Lapayre. They were made primarily to study the effects of cloudiness, high vapor-pressure, and humidity on solar radiation-measurements. The program and apparatus were essentially the same as those at Tamanrasset. The direct radiation at this station remained under 1.5 gr-cal/cm^2—min. Cloudiness had the effect of reducing the recorded values from 15 per cent for cirrus to 90 per cent in the case of cumulus. Measurements made in an airplane using a thermal electric cell and galvanometer demonstrate the possibilities of this type of measurement for determining the variations with altitude and the effect of clouds. The tables give detailed values for total radiation, and direct radiation, with and without filters from March 2 to July 13, 1933. Tables showing the insolation from August 1932 to July 1933 are also given.

The fourth section by J. Habert and M. Douguet, first summarizes the results of radio-electric observations made at Scoresby Sound. They included attempts to determine the height of the ionosphere, observations on the propagation of short waves, and recording of atmospherics. Attempts made between June 5 and August 7, 1933, to determine the ionospheric heights by reflection of a short pulse of wave-length 30 to 60 meters, frequency 10,000 to 5,000 kc sec, resulted in no echoes being received, indicating that, during this period, the critical frequency must have been less than 5000 kc/sec. The observations dealing with short-wave transmission are summarized in charts showing (1) the signal-strength as received hour by hour at Scoresby Sound from four transmitting stations in France on designated international days, (2) the number of European stations picking up signals transmitted from Scoresby Sound as a function of the hour of sending, (3) the strength of signals of several wave-lengths received at stated times once each day or oftener from stations in France, England, and Japan, and (4) similar data on the reception at Cherbourg of signals transmitted from Scoresby Sound. The daily records of atmospherics, too voluminous for reproduction, are summarized in charts.

The remainder of section four discusses in detail the instruments, methods, and results obtained and the connection of the results with the observations of solar, magnetic, and auroral activity. The relative influence of corpuscular and ultraviolet radiation on short-wave propagation and on atmospherics is also discussed and a number of suggestions is made for further work in this field.

The final section gives the history of the three expeditions. The portion dealing with Scoresby Sound is naturally the most extensive. The detailed account given by J. Habert of the construction, equipment, and operation of the station is not only interesting in itself but should prove valuable as a guide for future expeditions.

W. J. Rooney

(See also page 476)

THE NORTHERN LIGHT OF SEPTEMBER 27, 1938

On September 27, 1938, a very brilliant display of northern lights was observed at State College, Pennsylvania (latitude 40° 47′.8 north, longitude 77° 51′.8 west). The phenomenon was first observed as a faint gleam at $19^h\ 30^m$ 75° west meridian time and increased in brightness so that at $20^h\ 10^m$ there could no longer be any doubt that it was actually an aurora. It developed several arcs and streamers and became so pronounced that it was decided to take some measurements of its extent. These measurements started at $21^h\ 30^m$ and were continued until $23^h\ 15^m$. Thereafter the aurora became again very faint, although at $03^h\ 00^m$ on September 28 some light was still visible in the north.

Table 1 is a log of the observations. The aurora reached its most extended development between $22^h\ 34^m$ and $22^h\ 40^m$. During that interval more than three-fourths of the sky was luminous. Red, orange, and green colors were visible. A photograph of the streamer in the northwest was taken between $22^h\ 31^m$ and $22^h\ 41^m$ on a miniature camera $f=2.7$, on Kodak panchromatic film. In spite of the long exposure still some of the streamer structure is visible. The sky was cloudless all night long.

TABLE 1—*Observations of Aurora Borealis, September 27, 1938, State College, Pennsylvania*

75° west meridian time		Height arc above northern horizon				Limit at horizon in		Highest point above Southern horizon	Radiation-point
		First	Second	Third	Fourth	West	East		
h	*m*	°	°	°	°	°	°	°	°
21	30	11.5	......	......	......	......	......	70	......
21	40	11.0	24.2	40.6	56.5	......	......	66	......
21	50	......	......	......	......	W9N	E7N	......	......
21	52[a]	......	......	......	......	......	......	......	......
22	00[b]	......	......	......	......	......	......	......	......
22	15[c]	17.5	37.0	......	......	W4S	E9N	67.5	......
22	25[d]	......	......	......	......	......	......	......	......
22	32[e]	......	......	......	......	......	......	......	......
22	34[f]	......	......	......	......	......	......	......	......
22	36[g]	......	......	......	......	......	......	......	......
22	40[h]	......	......	......	......	......	......	......	......
22	43[i]	......	......	......	......	......	......	......	70 above S
22	45	7.0	12.0	26.7	55.5	......	......	34	......
22	48	......	......	......	......	W30S	E5N	......	......
22	50	......	......	......	......	......	......	......	74 above SSE
22	54	8.0	20.0	36.0	......	......	......	23.5	......
23	15	7.5	37	......	......	W8S	N30E	......	......

[a]Streamer in NE, height 30°-50°, flashes with period of 8 sec. [b]Brightness equal that of fourth-magnitude stars. [c]Aurora becomes diffuse. [d]Flashes with period of 16 sec. [e]Draperies in N and NW come up again. [f]In WNW bright green band shooting up 12° wide, develops red colors rapidly. [g]As bright as first-magnitude stars. [h]Flashes with period of ½ sec. [i]As bright as second-magnitude stars.

State College, Pennsylvania,
October 10, 1938

H. LANDSBERG AND H. H. NEUBERGER

REMARKS ON DR. CHAPMAN'S NOTE ON RADIO FADE-OUTS AND THE ASSOCIATED MAGNETIC DISTURBANCES

This letter is by way of an addendum to the communication of Professor S. Chapman[1] and the further communication by S. S. Kirby[2] which it prompted.

Mr. Kirby has given a useful analysis of the steps by which the relations between radio fade-outs and their associated solar and magnetic disturbances have been gradually elucidated during the last two and a half years by American workers, but the story seems to me to be incomplete, since no mention is made of the work of Mögel, the pioneer investigator of such matters.

In a paper published as early as 1930, Mögel[3] gives an analysis of what he calls "short disturbances", encountered in short-wave communication during the last sunspot-maximum period. Mögel, with a wealth of illustrative data, describes the characteristic sudden start of such fade-outs with the recovery for all stations within about an hour. He also shows that they occur only on the illuminated side of the Earth, and that they are frequently accompanied by characteristic variations of the horizontal component of the Earth's magnetic field, although the day in question may be otherwise classed as magnetically quiet. He suggests that the radio and magnetic effects are due to abnormal ionization of the lower layers of the atmosphere.

Attention has already been drawn by Dr. J. Bartels[4] to the classical instance of the association of a bright solar eruption observed by Carrington on September 1, 1859, and the small simultaneous magnetic disturbance disclosed by the Kew Observatory records, but it would scarcely be permissible to deduce from this single example and the work of Mögel the complete association of the three phenomena, fade-out, bright eruption, and magnetic disturbance. Such association has been satisfactorily established only as the result of the work of Dellinger, Jouaust, Fleming, Richardson, Newton, McNish, Torreson, Scott and Stanton, and Berkner and Wells.

Mr. Kirby's account of the early work on ionospheric perturbations associated with magnetic storms is likewise incomplete. That magnetic storms are usually accompanied by low region F_2 maximum electron-density and an inflated higher atmosphere was announced in *Nature* on October 5, 1935,[5] the deductions being made from an analysis of data for the whole year of 1934. Mr. Kirby's first reference citation[6] deals with a letter to the *Physical Review* on November 15, 1935, dealing independently with the single instance of a magnetic storm occurring on October 24, 1935. The important work of Harang[7] in Norway on this subject might well have been mentioned in Mr. Kirby's list.

E. V. Appleton

[1]Terr. Mag., **42**, 417-419 (1938).
[2]Terr. Mag., **42**, 420 (1938).
[3]Telefunken-Ztg., **11**, 14-31 (1930).
[4]Terr. Mag., **42**, 235-239 (1937).
[5]E. V. Appleton and L. J. Ingram, Nature, **136**, 548-549 (1935).
[6]S. S. Kirby, T. R. Gilliland, E. B. Judson and N. Smith, Phys. Rev., **48**, 849 (1935).
[7]L. Harang, Beitr. Geophys., **46**, 438-454 (1936).

AVERAGES OF CRITICAL FREQUENCIES AND VIRTUAL HEIGHTS OF THE IONOSPHERE, OBSERVED BY THE NATIONAL BUREAU OF STANDARDS, WASHINGTON, D. C., JULY TO SEPTEMBER, 1938[1]

The following ionosphere data are in continuation of those published for 1934-36 in this JOURNAL[2] and in each issue subsequently. The symbols used are:

h_E=E-region virtual height, kilometers (lowest measured height)
h_{F_1}=F_1-region virtual height, kilometers (lowest measured height)
h_{F_2}=F_2-region virtual height, kilometers (lowest measured height)
f_E=E-region critical frequency, kilocycles per second, ordinary ray
$f^\circ{}_{F_1}$=F_1-region critical frequency, kilocycles per second, ordinary ray
$f^x{}_{F_2}$=F_2-region critical frequency, kilocycles per second, extraordinary ray
EST=Eastern standard time (75° west meridian time); add five hours for Greenwich time
#=Manual measurements
*=Less than ten measurements with automatic recorder

TABLE 1—*Ionosphere data, National Bureau of Standards, Washington, D. C.*
(Averages for all days of the month including disturbed days)

EST	h_E	h_{F_1}	h_{F_2}	f_E	$f^\circ{}_{F_1}$	$f^x{}_{F_2}$	h_E	h_{F_1}	h_{F_2}	f_E	$f^\circ{}_{F_1}$	f^x
h			*July, 1938*						*August, 1938*			
00			298			7080			303			69
01			313			6550			302			66
02			304			6220			305			62
03			313			5850			306			58
04			321	1000#		5400			305	900#		54
05			307	1770#		5380			302	1250#		54
06		255	360*	2580		6290			250	2290	3788*	62
07	116	233	340#	2970		6850	117	234	302*	2850	4195	72
08	113	223	353#	3350		7290	111	219	321#	3251	4614#	77
09	112	216	355#	3630	5180#	7620	111	214	330#	3614	5000#	80
10	111	219	360#	3870	5310#	7770	110	205	358#	3853	5257#	81
11	111	204	409#	4020	5360#	7730	110	204	375#	3972	5400#	82
12	112	204	398#	4080	5360#	7740	111	205	380#	4029	5462#	83
13	112	212	415#	4070	5400#	7920	111	213	378#	4006	5400#	83
14	111	218	400#	4010	5360#	7800	111	217	382#	3888	5443#	84
15	112	226	381#	3820	5300#	7940	110	226	368#	3713	5383#	84
16	113	231	371#	3570	5170#	8180	113	228	352#	3418	5050#	85
17	114	228	361#	3210	4940#	8340	118	230	314#	3032	4495	85
18		248	315#	2700	4480#	8390		247	307	2435	3859	80
19			267	2150#		8450			263	1540#		87
20			266	1350#		8450			263			86
21			277			8100			272			82
22			291			7780			278			76
23			294			7450			292			72

[1]Communicated by the director of the National Bureau of Standards of the United States Department of Commerce.
[2]T. R. Gilliland, S. S. Kirby, N. Smith, and S. E. Reymer, Terr. Mag., **41**, 379-383 (1936).

TABLE 1—*Ionosphere data, National Bureau of Standards, Washington, D. C.*—Continued
(Averages for all days of the month including disturbed days)

EST	h_E	h_{F_1}	h_{F_2}	f_E	$f^o_{F_1}$*	$f^x_{F_2}$	Notes on May and June data
h			*September, 1938*				
00			311			6322	Corrigenda on page 327 of the September, 1938, issue of the JOURNAL, in Table 1.
01			305			6137	
02			307			5920	
03			303			5705	
04			312			5295	
05			311	950#		5032	*May, 1938*—$f^o_{F_1}$ for 06^h should read 3920* instead of 3920#.
06			259	1900#		6135	
07	120*	242	282#	2600		8043	
08	116	230	285#	3108		9010	
09	111	222	295#	3436		9542	*June, 1938*—$f^o_{F_2}$ for 18^h should read 4060* instead of 4060# and f_E for 19^h should read 2100* instead of 2100#.
10	110	215	305#	3662		9715	
11	110	212	313#	3781		9786	
12	111	214	323#	3821		10031	
13	112	221	320#	3785		10203	
14	111	228	303#	3665		10207	
15	114	230	303#	3426		10202	
16	117	236	291#	3091		10214	
17	113*	242	278#	2598		10183	
18			247	2000#		9852	
19			244			9307	
20			254			8567	
21			270			7713	
22			288			7037	
23			299			6547	

*F_1 critical frequencies not well defined during September.

NATIONAL BUREAU OF STANDARDS,
UNITED STATES DEPARTMENT OF COMMERCE.
Washington, D. C.

PROVISIONAL SOLAR AND MAGNETIC CHARACTER-FIGURES, MOUNT WILSON OBSERVATORY JULY, AUGUST, AND SEPTEMBER, 1938

Greenwich mean time							Range hor. int.
Beginning			Ending				
1938	*h*	*m*		*d*	*h*	*m*	γ
July 4	12	04		5	8	..	135
15	3	15		17	7	..	151
30	4	35*		30	13	..	109
Aug. 3	21	36*		4	11	..	187
11	3	22		11	19	..	117
22	13	53*		23	17	..	86
Sep. 13	18	37		15	24	..	155
26	7	25*		26	22	..	112
27	22	02*		28	10	..	177
30	10	22*	Oct.	1	10	..	174

* Sudden commencement

The storm of July 15-17 and that of August 11 were probably associated with the very large and active group which crossed the central meridian on July 15.1 and again on August 10.9.

The storms of September 26 and 27-28 were probably associated with two active groups which crossed the central meridian on September 25.6 and 28.0.

July 1938

Day	K_2 A	K_2 B	$H\alpha B$ A	$H\alpha B$ B	$H\alpha D$ A	$H\alpha D$ B	No. groups	Mag'c char.
1	3	3	3[c]	3	3	2	9	0.5
2	3	3	3[c]	3	3	3	10[b,o,i]	0.5
3	3	3	3	3[d]	3	2	9	0
4	3	2	3	2	3	2	9	1
5	3	2	3	2[d]	3	2	12	0.5
6	3	3	3	3	2	2	14	0.5
7	3	3	....	..[d]	....	....	17[f]	0
8	4	4	4	4	2	2	17	0
9	3	4	4[c]	4	2	2	15	0.5
10	4	4	4	4	2	1	15[h]	1
11	4	4	5	4	2	1	14	0
12	4	4	5	4[d]	2	0	14	0
13	4	4	4	4	2	1	14	0.5
14	4	4	4	4	2	2	15	0.5
15	4	4	4	4	2	2	16[h]	1.5
16	4	4	4	4	3	2	15	1
17	4	3	4	3	3	2	11	0
18	4	3	4	3	3	3	11	0
19	3	3	4	4	3	4	15	0
20	3	3	3	3	4	3	13	0
21	3	3	3	3	4	3	17	0
22	3	3	3	3	4	3	14[a]	0
23	3	4	4	4	4	4	17	0
24	4	4	4[c]	4	4	3	15[e]	0
25	4	4	4	4[d]	4	3	15	0
26	4	4	5[c]	3	4	2	13	0
27	4	3	4	3[d]	3	2	12	0
28	4	4	4	4	3	3	14	0
29	4	4	4[c]	4	3	2	12	0.5
30	3	3	3	3	3	3	9[o]	1
31	3	2	3[c]	2	3	2	8	0
Mean	3.5	3.4	3.7	3.4	2.9	2.3	13.3	0 3

August 1938

Day	K_2 A	K_2 B	$H\alpha B$ A	$H\alpha B$ B	$H\alpha D$ A	$H\alpha D$ B	No. groups	Mag'c char.
1	3	2	3	2[d]	3	3	13	0.5
2	3	2	3	2	3	2	10	1
3	3	2	3	2	2	1	11[b]	1
4	3	3	3	3	3	2	15	1.5
5	....	....	....	....	....	....	13	0.5
6	5	5	4	4	2	2	11	0
7	5	4	4	4	2	2	11	0.5
8	5	4	4	3	3	1	13	0
9	5	5	4	4	3	2	15	0
10	5	4	4	4	2	2	13[i]	0.5
11	4	4	4	4	2	3	16	1.5
12	4	3	4	3	2	2	14	0.5
13	4	2	4	2	2	2	14	0.5
14	4	3	4	2	3	3	9[k]	0
15	3	2	3	2	3	2	13	0
16	3	3	3	3	3	3	12	0
17	3	3	3	3	4	3	12	0
18	3	4	4	4	4	3	11	0
19	3	4	4	4	4	4	12	0
20	3	3	4	4	4	3	12	0
21	4	3	4	3	4	3	11	0
22	4	3	4	3	4	4	11[a]	0.5
23	4	3	4	3	4	3	10[l]	1
24	4	4	4	4	4	4	11	0.5
25	3	4	4	4	4	3	15	0
26	4	3	4	4	4	4	13	0
27	4	4	4	4	3	2	11	0
28	....	....	....	....	....	....	13	0.5
29	4	3	4	3	3	1	14	0.5
30	4	3	4	4	3	2	12	0
31	4	4	4	4	3	2	9	0
Mean	3.8	3.3	3.8	3.3	3.1	2 5	12 3	0 4

September 1938

Day	K_2 A	K_2 B	$H\alpha B$ A	$H\alpha B$ B	$H\alpha D$ A	$H\alpha D$ B	No. groups	Mag'c char
1	4	4	4	4	3	2	11	0
2	4	4	4	4	3	1	11	0
3	5	5	4	4	3	1	11[f]	0.5
4	5	4	5	4	2	0	8	0
5	5	4	5	4	3	1	7[f]	0.5
6	4	4	5	4	3	2	8	0
7	4	4	4	4	3	3	6	0.5
8	3	3	3	3	3	3	6	0
9	3	2	3	2	3	3	6	0.5
10	3	1	3	1	3	4	7	0
11	2	1	2	1	2	3	7	0.5
12	....	....	2	2	2	1	5	0
13	2	2	3	3	2	2	4	0.5
14	....	....	....	....	....	....	3	1
15	3	4	3	4	3	2	4	1.5
16	3	3	3	3	3	2	4[e]	0.5
17	....	....	....	....	....	....	....	0.5
18	3	2	....	....	....	....	3	0
19	3	2	3	2	4	5	8	0
20	....	....	....	....	....	....	7	0.5
21	3	3	3	3	4	4	8	0
22	3	2	3	3	4	3	6	0.5
23	....	....	3	2	4	3	7	0.5
24	3	3	3	3	4	2	11	0
25	3	3	4	4	3	0	13[a,h]	0
26	4	4	4	4	4	2	13	1
27	....	....	....	....	....	....	12	0.5
28	....	....	....	....	....	....	....[h]	1
29	....	....	....	....	....	....	13[b]	0.5
30	5	4	5	4	4	2	12	1
Mean	3.5	3.1	3.5	3.1	3.1	2.2	7.9	0.4

NOTE—For an explanation of these tables see this JOURNAL, **35**, 47-49 (1930).

The character-figures of solar phenomena are estimated from the spectroheliograms which are made with a 2-inch solar image, usually in the early morning. Very bright chromospheric eruptions are reported in these notes if observed at any time during the day.

[a], [b] Formation of a new group which later developed to average size or larger; (*a*) less than 30° from the center of the disk, (*b*) more than 30° from the center of the disk.

[c], [d] Very bright chromospheric eruptions; (*c*) less than 30° from the center of the disk, (*d*) more than 30° from the center of the disk.

[e], [f], [o], [h], [i], [j], [k], [l] Passage of a large or active group across the central meridian within 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40° of the center of the disk, respectively.

CARNEGIE INSTITUTE OF WASHINGTON,
MOUNT WILSON OBSERVATORY,

SETH B. NICHOLSON

AMERICAN *URSI* BROADCASTS OF COSMIC DATA[1], JULY TO SEPTEMBER, 1938, WITH AMERICAN MAGNETIC CHARACTER-FIGURE C_A, AUGUST TO OCTOBER, 1938

The data for terrestrial magnetism, sunspots, and solar constant are the same as given in previous tables.

[1]For previous announcements see Terr. Mag., **35**, 184-185 and 252-253 (1930); **36**, 54, 141, 258-259, and 358-360 (1931); **37**, 85-89, 189-192, 409-411, and 484-487 (1932); **38**, 60-63, 148-151, 262-265, 335-339 (1933); **39**, 73-77, 159-163, 244-247, 353-356 (1934); **40**, 111-115, 220-222, 334-336, 449-452 (1935); **41**, 85-87, 207-209, 315-317, 407-409 (1936); **42**, 89-91, 207-209, 316-319, and 411-415 (1937); **43**, 83-87, 174-178, and 328-331 (1938).

Summary American URSI daily broadcasts of cosmic data, July to September, 1938

Greenwich date	July					August					September				
	Magnetism			Sunspot		Magnetism			Sunspot		Magnetism			Sunspot	
	Character	Type	GMT beginning disturbance	Groups	Number	Character	Type	GMT beginning disturbance	Groups	Number	Character	Type	GMT beginning disturbance	Groups	Number
			h m					h m					h m		
1	1	...	.. ..	9	140	1	*i*	7 46	13	80	0	...	.. ..	11	125
2	1	...	.. ..	10	135	1	*i*	.. ..	10	65	0	...	.. ..	11	60
3	0	...	.. ..	9	115	2	*i*	21 36	11	55	0	...	.. ..	11	110
4	1	*i*	12 04	9	155	2	*i*	23 47	15	70	0	...	.. ..	8	100
5	1	*i*	.. ..	12	95	1	*i*	.. ..	13	a	0	...	.. ..	7	75
6	0	...	.. ..	14	150	1	...	.. ..	11	45	0	...	.. ..	8	125
7	0	...	.. ..	17	130	0	...	.. ..	11	65	0	...	.. ..	6	120
8	0	...	.. ..	17	100	0	...	.. ..	13	110	0	...	.. ..	6	75
9	1	*i*	19 54	15	160	0	...	.. ..	15	100	0	...	.. ..	6	60
10	1	*i*	.. ..	15	180	0	...	.. ..	13	85	0	...	.. ..	7	55
11	0	...	.. ..	14	360	1	*i*	4 23	16	100	0	...	.. ..	7	40
12	0	...	.. ..	14	310	1	...	.. ..	14	75	0	...	.. ..	5	20
13	1	*i*	20 04	14	305	1	...	.. ..	14	55	1	*i*	18 38	4	40
14	1	*i*	.. ..	15	310	0	...	.. ..	9	50	2	*i*	15 32	.	..
15	2	*i*	3 15	16	205	0	...	.. ..	13	55	2	*i*	.. ..	...	..
16	1	*i*	.. ..	15	125	0	..	.. ..	12	60	1	*i*	.. ..	4	50
17	1	*i*	.. ..	...	...	0	...	.. ..	12	40	0	.	. .	.	..
18	0	...	.. ..	11	110	0	...	.. ..	11	135	0	...	.. ..	3	25
19	0	...	.. ..	15	70	0	...	.. ..	12	110	0	...	.. ..	8	55
20	0	...	.. ..	13	50	0	..	.. ..	12	60	0	...	.. ..	7	40
21	0	...	.. ..	17	80	0	...	.. ..	11	50	0	...	.. ..	8*	40
22	0	...	.. ..	14	105	1	*i*	13 56	11	55	1	...	.. ..	6	75
23	0	...	.. ..	17	165	1	*i*	.. ..	10	75	0	...	.. ..	7	100
24	0	...	.. ..	15	110	0	...	.. ..	11	75	0	...	.. ..	11	100
25	0	...	.. ..	15	175	0	...	.. ..	15	105	0	...	.. ..	13	140
26	0	...	.. ..	13	a	0	...	.. ..	13	115	1	*i*	7 25	13	145
27	0	...	.. ..	12*	a	0	...	.. ..	11	95	2	*i*	22 02	..	...
28	0	...	.. ..	14	a	0	...	.. ..	13	70	2	*i*	.. ..	..	..
29	0	...	.. ..	12	110	0	...	.. ..	14	115	1	*p*	.. ..	.	.
30	2	*i*	4 36	9	100	0	...	.. ..	12	105	1	*p*	10 22	12	175
31	0	...	.. ..	8	70	0	...	.. ..	9	110					
Mean	0.5	...	.. ..	...	...	0.4	...	.. ..	...	...	0.5	...	.		

*Revision of value originally broadcast.

[a]Quality of negatives too poor to count the number of spots.

Greenwich mean time for ending of storms: 07h, July 5; 24h, July 10; 06h, July 14; 07h, July 17; 13h, July 30; 07h, August 2; 11h, August 4; 09h, August 5; 18h, August 11; 24h, August 23; 05h, September 14; 04h, September 16; 24h, September 26; 09h 30m, September 28; 05h, October 2.

The first three columns of the Table give (1) the magnetic character according to the scale 0-2 of the International Commission of Terrestrial Magnetism and Atmospheric Electricity, (2) the type featuring the day other than normal by the letters *b*, *p*, *o*, and *i* for days marked by bay, rapid pulsations, long-period oscillations, and irregular oscillations, respectively, and (3) the hour and minute of Greenwich mean time marking the beginning of a storm, the end of the storm being indicated in the foot-note to the Table. The next two columns give the data relating to sunspots: (1) the number of groups of spots and (2) the total number of spots. It is to be noted that sunspot-numbers such as those from Zürich can be obtained from the number of groups and spots given in the Table by the formula $N = k\ (10g + s)$, where the mean value of k for Mount Wilson was 0.53 during 1936; during 1937 this value varied from 0.47 to 0.66 with an average value of 0.53.

American magnetic character-figure C_A for Greenwich half-days based on reports from Cheltenham, Honolulu, Huancayo, San Juan, Sitka, Tucson, and Watheroo for August to October, 1938

Day	August		September		October	
	0^h-12^h	12^h-24^h	0^h-12^h	12^h-24^h	0^h-12^h	12^h-24^h
1	0.7	0.8	0.0	0.0	1.3	0.6
2	0.9	0.5	0.1	0.1	0.4	0.2
3	0.3	1.3	0.5	0.2	0.3	0.3
4	1.6	0.9	0.1	0.4	0.3	0.2
5	0.9	0.7	0.3	0.4	0.0	0.1
6	0.5	0.1	0.0	0.1	0.3	0.4
7	0.4	0.4	0.4	0.4	0.8	1.4
8	0.2	0.1	0.1	0.3	1.6	0.6
9	0.0	0.0	0.1	0.4	0.4	0.2
10	0.8	0.6	0.1	0.1	0.1	0.1
11	1.2	1.3	0.0[a]	0.2	0.2	0.1
12	0.7	0.5	0.1	0.1	0.0	0.0
13	0.6	0.1	0.4	0.8	0.0	0.0
14	0.1	0.1	1.0	1.2	0.0	0.0
15	0.0	0.0	1.7	1.6	0.0	0.0
16	0.0	0.0	0.4	0.4	0.1	0.5
17	0.0	0.1	0.3	0.1	0.1	0.1
18	0.1	0.0	0.0	0.0	0.0	0.1
19	0.0	0.0	0.0	0.0	0.2	0.4
20	0.0	0.0	0.3	0.2	0.4	0.4
21	0.0	0.2	0.0	0.2	0.0	0.0
22	0.0	1.1	0.5	0.1	0.0	0.0
23	1.1	0.7	0.6	0.1	0.5	0.6
24	0.2	0.6	0.0	0.0	0.2	0.8
25	0.2	0.0	0.0	0.2	1.0	0.7
26	0.0	0.0	0.9	0.9	0.8	0.9
27	0.0	0.0	0.5	1.0	1.0	0.9
28	0.0	0.6	1.6	0.7	0.6	0.7
29	0.6	0.4	0.6	0.4	0.1	0.3
30	0.4	0.1	0.5	1.1	0.1	0.1
31	0.1	0.0			0.0	0.0
Means	0.4	0.4	0.4	0.4	0.3	0.3
	0.4		0.4		0.3	

[a]San Juan not reporting.

Mount Wilson Observatory is now supplying corrections and additions to the sunspot-data which are broadcast in the *URSI*gram. So far as possible, these additional and corrected values will be used in this tabular summary and will be designated as such in foot-notes to the Table.

Kennelly-Heaviside Layer heights, Washington, D. C., July to September, 1938
(Nearest hour, Greenwich mean time, of all observations is 17)

Date	Freq.	Ht.	Date	Freq.	Ht.	Date	Freq.	Ht.	Date	Freq.	Ht.
1938	*kc/sec*	*km*	*1938*	*kc sec*	*km*	*1938*	*kc sec*	*km*	*1938*	*kc sec*	*km*
July 6	2,500	120	July 27	4,600	230	Aug. 17	5,800	380	Sep. 7	9,800	460
" "	4,200	120	" "	5,400	360	" "	6,600	360	" "	10,200	420
" "	4,200	220	" "	5,600	350	" "	7,800	400	" "	10,200	610
" "	4,400	120	" "	6,400	350	" "	7,800	460	" "	10,800	490
" "	4,400	210	" "	6,800	420	" "	8,200	430	" "	11,000	*
" "	5,400	390	" "	7,200	430	" "	8,200	690	" 14	2,500	110
" "	5,800	440	" "	7,200	460	" "	8,800	540	" "	3,500	140
" "	6,400	410	" "	7,600	440	" "	9,000	*	" "	3,550	270
" "	7,200	450	" "	7,600	610	" 24	2,500	110	" "	4,250	210
" "	7,200	510	" "	8,000	460	" "	3,500	110	" "	4,400	240
" "	7,400	440	" "	8,200	500	" "	3,820	150	" "	4,600	280
" "	7,400	700	" "	8,400	*	" "	3,900	270	" "	5,400	290
" "	7,800	460	Aug. 3	2,500	110	" "	4,250	190	" "	5,800	330
" "	8,000	510	" "	4,400	110	" "	4,400	220	" "	7,000	330
" "	8,200	*	" "	5,000	130	" "	5,200	210	" "	8,000	380
" 13	2,500	120	" "	5,200	290	" "	5,200	310	" "	8,400	380
" "	4,100	120	" "	5,600	300	" "	6,200	300	" "	8,400	450
" "	4,200	120	" "	6,000	450	" "	7,000	320	" "	9,000	410
" "	4,200	270	" "	6,400	420	" "	7,800	380	" "	9,000	680
" "	4,300	120	" "	7,200	450	" "	8,400	390	" "	9,800	560
" "	4,300	200	" "	7,200	620	" "	8,400	470	" "	9,900	*
" "	5,000	260	" "	7,600	500	" "	9,200	510	" 21	2,500	110
" "	5,400	600	" "	8,000	630	" "	9,400	*	" "	3,600	150
" "	5,800	430	" "	8,200	*	" 31	2,500	110	" "	3,700	270
" "	6,400	460	" 10	2,500	110	" "	3,500	130	" "	3,900	210
" "	6,800	500	" "	3,500	120	" "	3,800	170	" "	5,000	250
" "	7,000	450	" "	3,950	170	" "	3,950	220	" "	6,000	290
" "	7,000	560	" "	4,000	*	" "	4,200	190	" "	8,000	300
" "	7,400	480	" "	4,120	270	" "	4,600	240	" "	8,800	330
" "	7,800	590	" "	4,250	230	" "	5,200	220	" "	8,800	390
" "	8,000	*	" "	5,600	500	" "	5,200	290	" "	9,800	350
" 20	2,500	110	" "	5,800	510	" "	5,800	270	" "	9,800	470
" "	4,800	120	" "	6,200	440	" "	5,800	370	" "	10,600	480
" "	5,000	250	" "	6,400	450	" "	6,400	370	" "	10,800	*
" "	5,800	410	" "	6,400	520	" "	7,600	420	" 28	2,500	110
" "	6,000	410	" "	7,000	450	" "	7,600	540	" "	3,650	180
" "	6,600	380	" "	7,000	640	" "	8,600	510	" "	3,750	130
" "	7,000	400	" "	7,400	490	" "	8,800	*	" "	3,820	270
" "	7,800	430	" "	7,800	780	Sep. 7	2,500	110	" "	3,900	230
" "	7,800	470	" "	8,000	*	" "	3,650	130	" "	4,600	270
" "	8,200	460	" 17	2,500	120	" "	3,800	*	" "	5,600	290
" "	8,200	640	" "	3,500	120	" "	3,950	230	" "	5,600	370
" "	8,800	500	" "	3,800	130	" "	4,400	210	" "	7,000	410
" "	9,000	*	" "	4,000	*	" "	5,600	240	" "	7,800	410
" 27	2,500	110	" "	4,100	200	" "	5,600	300	" "	7,800	550
" "	3,500	110	" "	4,400	230	" "	6,600	300	" "	8,400	460
" "	4,000	150	" "	5,200	220	" "	6,600	330	" "	8,800	660
" "	4,050	*	" "	5,200	290	" "	8,600	350	" "	9,000	*
" "	4,200	110	" "	5,800	280	" "	9,800	400			

* = No value obtained.

Beginning January 1, 1934, the magnetic information of the *URSI*-gram is for Cheltenham, Maryland, instead of Tucson, Arizona. In addition to this change in observatory, beginning November 1, 1937, the data cover the 24 hours of the Greenwich day ending at 19^h, 75° west meridian mean time instead of the 24 hours ending at 8^h, 75° west meridian mean time.

In accordance with information received from Dr. C. G. Abbot, Secretary of the Smithsonian Institution, on March 6, 1937, solar-constant values were discontinued owing to important change in methods.

The data for the table of Kennelly-Heaviside Layer heights which is self-explanatory are supplied by the National Bureau of Standards.

As set forth in this Journal for June, 1937, "The Department of Terrestrial Magnetism and United States Coast and Geodetic Survey with the coperation of the United States Army and United States Navy communication-services and several amateur radio stations have undertaken to supply the American character-figure based upon the reports of the seven American-operated observatories—those of the Department of Terrestrial Magnetism at Huancayo in Peru and at Watheroo in Western Australia, and those of the United States Coast and Geodetic Survey at Cheltenham (Maryland), Honolulu (Hawaii), San Juan (Puerto Rico), Sitka (Alaska), and Tucson (Arizona)." This character-figure is being designated C_A, and the values for August to October, 1938, are given in the accompanying Table.

H. F. Johnston

Department of Terrestrial Magnetism,
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Washington, D. C.

PRINCIPAL MAGNETIC STORMS

Sitka Magnetic Observatory
July to September, 1938

(*Latitude 57° 03′.0 N., longitude 135° 20′.1 or 9^h $01^m.3$ W. of Gr.*)

July 4-5—A slight magnetic disturbance began gradually at about 03^h GMT, July 4, and increased slowly to maximum intensity between 12^h and 14^h. Thereafter the elements gradually returned to normal values at about 07^h GMT, July 5. Ranges: D, 79′; H, 553 gammas; Z, 488 gammas.

July 15-16—A moderate magnetic disturbance occurred during the latter part of July 15. The beginning and most of the disturbance was lost because of a failure of the recording drum. The latter part of the disturbance was marked by rapid short-period vibrations superimposed on large bays. The elements had returned to normal by 24^h GMT, July 16. Ranges: D, 100′; H, 699 gammas; Z, 519 gammas.

July 30-31—A small magnetic storm began abruptly at 04^h 34^m GMT, July 30, with a sharp increase of 54 gammas in H. The storm continued until about 11^h 30^m when the elements returned to about normal. The trace remained moderately disturbed until 04^h GMT, July 30; at this time the trace was again normal. The disturbance was accompanied by a very brilliant auroral display. Ranges: D, 154′; H, 1666 gammas; Z, 518 gammas.

August 3-6—A moderate magnetic storm began abruptly at $21^h\ 36^m$ GMT, August 3, with a sharp increase of 21′ in east declination. The storm increased to maximum intensity between 05^h and 14^h, August 4. Thereafter the disturbance continued moderately disturbed until about 10^h, August 6. Ranges: *D*, 126′; *H*, 1259 gammas; *Z*, 576 gammas.

August 10-11—A small magnetic storm began abruptly with a sudden increase of about 60 gammas in *H* at $03^h\ 22^m$ GMT, August 10. The trace continued moderately disturbed until 08^h, August 11, when it rapidly increased in intensity to maximum values between 10^h and 16^h. Thereafter the elements returned slowly to normal values at 24^h, August 11. Ranges: *D*, 87′; *H*, 930 gammas; *Z*, 945 gammas.

August 22-23—A moderate magnetic disturbance began at $13^h\ 52^m$ GMT, August 22, with a small but sharp movement on all components. The disturbance continued with small amplitudes to a sharp bay between 09^h and 11^h, August 23. The disturbance gradually subsided and ended about 24^h, August 23. Ranges: *D*, 80′; *H*, 573 gammas; *Z*, 592 gammas.

September 13-16—A major magnetic storm began at $18^h\ 37^m$ GMT, September 13, with a sudden movement in the three components. The trace continued moderately disturbed with slightly increasing storminess. Both *H* and *Z* progressed to minimum values at about 18^h, September 14. Then both elements increased to maximum values at about 05^h, September 15. Beginning at $07^h\ 58^m$, September 15, with an abrupt decrease of about 760 gammas in *H* and corresponding movements in the other components, the principal part of the storm began. For the next eight hours the traces moved so rapidly that it was impossible to follow parts of the movement, as the lines did not record because of the fast motion. After 16^h, September 15, the elements gradually returned to normal values. The storm ended about 04^h, September 16. Ranges: *D*, 181′; *H*, 2097 gammas; *Z*, 1373 gammas.

September 23—A sudden commencement was noted at $04^h\ 35^m$ GMT. The components continued very slightly disturbed for about the next twenty hours.

September 26—A slight magnetic disturbance began gradually at $07^h\ 24^m$ GMT. *H* and *Z* decreased steadily for the next two hours; at $10^h\ 00^m$ there occurred a sharp decrease of 77′ in east declination. Until $13^h\ 20^m$ the trace continued disturbed; thereafter the elements gradually returned to normal. The disturbance ended about 24^h, September 26. Ranges: *D*, 154′; *H*, 744 gammas; *Z*, 616 gammas.

September 27—The trace continued only very slightly disturbed after the preceeding disturbance until 08^h GMT, September 27. Then conditions gradually became more disturbed. At $22^h\ 02^m$ a sudden movement started the principal part of the storm. The traces moved with a short-period vibration superimposed on a long-period motion. The disturbance ended at 22^h, September 27. Ranges: *D*, 49′; *H*, 266 gammas; *Z*, 279 gammas.

September 30-October 1—A small magnetic disturbance began abruptly at $10^h\ 21^m$ GMT, September 30, with a sharp movement. The disturbance gradually increased in intensity during the next few hours, reaching maximum values about 04^h, October 1. Thereafter the elements gradually returned to normal and the disturbance ended about 12^h, October 1. Ranges: *D*, 61′; *H*, 702 gammas; *Z*, 453 gammas.

ROBERT E. GEBHARDT, *Observer-in-charge*

Cheltenham Magnetic Observatory
July to September, 1938

(*Latitude 38° 44′.0 N., longitude 76° 50′.5 or 5*^{h} *07*^{m}*.4 W. of Gr.*)

July 4-5—A storm began abruptly July 4 at 12^{h} 04^{m} GMT, with an increase of 9 gammas in H and small changes in D and Z. The perturbations were irregular and ended at 07^{h}, July 5. Between 20^{h} and 24^{h}, July 4, was the time of greatest activity. Ranges: D, 26′; H, 232 gammas; Z, 122 gammas.

July 9-10—A sudden commencement of a mild disturbance took place at 19^{h} 52^{m} GMT, July 9. The disturbance continued until 24^{h}, July 10. Ranges: D, 26′; H, 147 gammas; Z, 61 gammas.

July 13-17—A disturbed period lasting several days began abruptly July 13 at 20^{h} 04^{m} GMT. The perturbations were of moderate intensity, the most disturbed period occurring between 06^{h} and 24^{h}, July 15. The ranges during this period were: D, 37′; H, 286 gammas; Z, 278 gammas. The disturbance ended at 07^{h}, July 17.

July 30-31—A storm began with an abrupt increase in H of 48 gammas at 04^{h} 35^{m} GMT, July 30. It ended at 05^{h}, July 31. Ranges: D, 40′; H, 202 gammas; Z, 289 gammas.

August 3-5—A storm with a sudden commencement occurred August 3-5, beginning at 21^{h} 36^{m} GMT, August 3, when H decreased abruptly 37 gammas followed by an equally abrupt increase of 170 gammas, and D and Z changed similarly by small amounts. The perturbations were irregular and the storm ended at 09^{h}, August 5. Ranges: D, 42′; H, 287 gammas; Z, 307 gammas.

August 10-12—A disturbance began at 03^{h} 22^{m} GMT, August 10, with a distinct but not abrupt commencement. The disturbance continued until 12^{h}, August 12. Ranges: D, 30′; H, 207 gammas; Z, 142 gammas.

August 22-24—A mild disturbance began at 13^{h} 54^{m} GMT, August 22, with a sudden commencement. The abrupt changes in D were more marked than those in H and Z. The disturbance ended at 02^{h}, August 24. Ranges: D, 28′; H, 184 gammas; Z, 110 gammas.

September 13-14—A mild storm began with a sudden commencement at 18^{h} 38^{m} GMT, September 13. The disturbance continued until 04^{h}, September 16. Ranges: D, 24′; H, 222 gammas; Z, 143 gammas.

September 26—A mild storm began abruptly at 07^{h} 26^{m} GMT, September 26. The ranges were not great but short-period activity continued throughout the disturbance which ended at 24^{h} the same day.

September 27-29—A disturbance began abruptly at 22^{h} 02^{m} GMT, September 27, and continued with mostly short-period oscillations until 24^{h}, September 29. The outstanding features of the disturbance were the sudden commencement and comparatively large swings in all the elements between 03^{h} 30^{m} and 04^{h}, September 28. Ranges: D, 49′; H, 346 gammas; Z, 188 gammas.

September 30-October 2—A disturbance characterized by short-period oscillations began abruptly at 10^{h} 22^{m} GMT, September 30, and ended at 05^{h}, October 2. The greatest ranges of the storm occurred between 03^{h} and 06^{h}, October 1. Ranges: D, 39′; H, 210 gammas; Z, 153 gammas.

Albert K. Ludy, *Observer-in-Charge*

Tucson Magnetic Observatory
July to September, 1938
(*Latitude 32° 14′.8 N., longitude 110° 50′.1 or $7^h\ 23^m.3$ W. of Gr.*)

July 4-5—A moderate storm began gradually July 4, about 12^h GMT, and ended about 08^h, July 5. The activity was mostly of the short, quick, saw-tooth variety, affecting *H* chiefly, *D* moderately, and *Z* slightly.

July 14-17—A period of moderate disturbance began with very slight activity about 20^h GMT, July 14. The activity increased gradually to a maximum about twenty-four hours after the beginning, then gradually diminished until the end at about 07^h, July 17.

July 30—Preceded by twelve hours or so of slight activity, a moderate disturbance began sharply at $04^h\ 36^m$ GMT, July 30, and ended on the same day at about $12^h.5$, almost as abruptly as it had begun. Long-period oscillations were predominant.

August 3-4—A moderate disturbance began sharply at $21^h\ 35^m$ GMT, August 3, with a sudden increase of 85 gammas in *H*. Thereafter for about seven hours there was only moderate activity consisting mostly of short-period variations in *H*. From about 05^h until about 10^h, August 4, the amplitudes were larger and the periods longer. The disturbance ceased to be of storm-proportions at about 10^h.

September 13-16—A period of moderate disturbance began rather definitely at about $18^h\ 37^m$ GMT, September 13, and ended very indefinitely about 04^h, September 16. There was no violent activity, chiefly long-period fluctuations in *H*, though several times *D* executed rather large movements. *H* was considerably depressed throughout most of the period.

September 27-28—A moderately severe storm beginning September 27, at 22^h GMT, lasted for roughly twelve hours. There were several large bays in *H* and the average value of this element fell considerably below normal. Slight activity continued for one day after the storm proper had ended.

September 30-October 1—An abrupt rise in *H* of about 29 gammas marked the beginning, at $10^h\ 20^m$ GMT, September 30, of another period of moderate disturbance which lasted until about 10^h, October 1. Saw-tooth oscillations predominated. The average value of *H* decreased considerably below normal, reaching a rather sharp minimum about 05^h before the end of the storm. At 04^h east declination suddenly lunged to a rather sharp maximum about 22′ above normal.

John Hershberger, *Observer-in-Charge*

Huancayo Magnetic Observatory
July to September, 1938
(*Latitude 12° 02′.7 S., longitude 75° 20′.4 or $5^h\ 01^m.4$ W. of Gr.*)

July 4-5—A sudden commencement occurred at $12^h\ 03^m$ GMT, July 4. In a period of three minutes *D* moved east 2′, *H* increased 28 gammas, and *Z* showed only a slight effect. Following this a magnetic storm continued until 06^h, July 5. Ranges: *D*, 7′.9; *H*, 272 gammas; *Z*, 43 gammas.

July 9—A sudden commencement occurred at $19^h\ 52^m$ GMT, July 9. In a period of four minutes *D* moved west very slightly, *H* decreased

2 gammas and increased 56 gammas, and Z increased 6 gammas. Following this the traces were only slightly disturbed.

July 13—A sudden commencement occurred at 20^h 04^m GMT, July 13. In a period of three minutes D moved west $0'.5$, H increased 60 gammas, and Z increased 7 gammas. The traces were only slightly disturbed afterward.

July 15-16—After several hours of only moderate disturbance, a magnetic storm began at 12^h GMT, July 15, continuing until 02^h, July 16. During this period a large number of fluctuations in H occurred, and its value was very low between 20^h 50^m, July 15 and 01^h 30^m, July 16. Ranges: D, $9'.1$; H, 340 gammas; Z, 52 gammas.

July 16—The traces were moderately disturbed from 12^h GMT to 20^h, July 16.

July 30-31—A sudden commencement occurred at 04^h 36^m GMT, July 30. In a period of five minutes D was not affected, H increased 34 gammas, and Z increased 7 gammas. A moderate disturbance followed continuing until 01^h, July 31.

August 3-5—At 21^h 35^m GMT, August 3, a sudden commencement occurred. During a period of two minutes D moved west $1'.2$, H increased 86 gammas, and Z increased 12 gammas. Moderate disturbances continued through August 4 and 5.

August 10-12—At 03^h 22^m GMT, August 10, a sudden commencement occurred in H and Z of relatively small magnitude. During a period of four minutes H increased 21 gammas and Z increased 4 gammas. Another slight sudden commencement occurred approximately twenty-four hours later at 03^h 23^m, August 11, when during a period of three minutes H increased 31 gammas, Z increased 5 gammas, and D was not affected. Following this the traces were moderately disturbed through August 11 and 12, particularly from 10^h to 19^h, August 11, when a number of large oscillations took place in H.

August 22-23—At 13^h 54^m GMT, August 22, a sudden commencement occurred when during a period of four minutes D moved west $1'.0$ and then east $4'.5$, H decreased 59 gammas and increased 181 gammas, and Z increased 8 gammas. A magnetic storm of moderate intensity continued until 21^h, August 22, during which a number of rapid oscillations occurred in H. Moderate disturbances of smaller amplitude continued through August 23.

September 13-15—At 18^h 37^m GMT, September 13, a sudden commencement occurred. During a period of four minutes D moved westerly $0'.5$ and then easterly $2'.0$, H decreased 9 gammas and then increased 148 gammas, Z increased 12 gammas. A moderate magnetic storm continued through September 13, 14, and 15. Ranges: D, $11'.1$; H, 424 gammas; Z, 45 gammas.

September 20—At 17^h 46^m GMT, September 20, a sharp increase in H occurred culminating at 17^h 55^m, following which conditions were quiet.

September 23—At 04^h 36^m GMT, September 23, a sudden commencement of small amplitude occurred. During a period of three minutes D moved westerly slightly, H increased 21 gammas, Z increased 4 gammas. A moderate disturbance continued until 21^h.

September 27-28—A sudden commencement occurred at 22^h 02^m GMT, September 27. During a period of four minutes D moved easterly $1'.4$, H increased 76 gammas, Z increased 10 gammas. A moderate storm of considerable intensity continued till 06^h, September 28, mod-

erate disturbance followed until 20^h. Ranges: D, 9′.7; H, 494 gammas; Z, 45 gammas.

September 30-October 1—At 10^h 21^m GMT, September 30, a sudden commencement of small amplitude in H and Z occurred. During a period of two minutes H increased 24 gammas and Z increased 4 gammas. Following this a magnetic storm of moderate intensity characterized by large fluctuations in H continued until 05^h, October 1. Ranges: D, 7′.6; H, 434 gammas; Z, 61 gammas.

Frank T. Davies, *Observer-in-Charge*

Watheroo Magnetic Observatory
July to September, 1938

(*Latitude 30° 19′.1 S., longitude 115° 52′.6 or 7^h 43^m.5 E. of Gr.*)

July 9-10—A sudden commencement occurred at 19^h 51^m GMT, July 9. D, after a slight easterly movement, moved westerly 2′.0 in four minutes, H increased 14 gammas in five minutes, and Z, after a slight numerical increase, decreased 13 gammas in four minutes. Moderately disturbed conditions prevailed for 24 hours.

August 22—Following a sudden commencement at 13^h 54^m GMT, August 22, D moved eastward 2′.0 in two minutes and then westward 2′.0 in three minutes, H increased 36 gammas in three minutes, and the numerical value of Z decreased 15 gammas in two minutes and then slightly increased. The traces were slightly disturbed for seven hours.

September 13-14—Following a sudden commencement at 18^h 36^m GMT, September 13, D moved easterly 3′.0 in four minutes followed by a gradual westerly movement in the next twenty minutes, H increased 51 gammas in four minutes followed by a gradual increase during the next hour, and the numerical value of Z decreased 23 gammas in four minutes followed by a gradual increase in the next four hours. The traces were moderately disturbed until 05^h, September 14.

September 26—There was a sudden commencement at 07^h 23^m GMT, September 26. D, after a sudden westerly movement of 0′.4, moved easterly 3′.0 in six minutes followed by rapid fluctuations. H, after a sudden decrease of 3 gammas, increased 25 gammas in three minutes followed by a decrease with small fluctuations during the next five hours. The numerical value of Z after an increase of 1 gamma decreased 14 gammas in five minutes followed by a gradual increase during the next six hours. Until about 21^h, the traces were moderately disturbed.

September 27-28—Following a sudden commencement at 22^h 02^m GMT, September 27, D, after a sudden westerly movement of approximately 2′.0, moved easterly 9′.0 in four minutes, H increased 54 gammas in three minutes and decreased sharply in the next eleven minutes, and the numerical value of Z after a sudden increase of 4 gammas, decreased 49 gammas in three minutes. Moderately disturbed conditions followed, H having small and rapid fluctuations. The disturbance ended at 14^h, September 28.

September 30-October 1—Following a sudden commencement at 18^h 20^m GMT, September 30, D moved 2′.0 easterly suddenly and 4′.0 westerly in two minutes, H increased 20 gammas in one minute, and the numerical value of Z decreased 7 gammas suddenly and then increased 14 gammas in two minutes. Moderately disturbed conditions prevailed during the next 23 hours.

J. W. Green, *Observer-in-Charge*

Magnetic Observatory, Capetown
April to June, 1938

(*Latitude 33° 57′ S., longitude 18° 28′ or 1^h $13^m.9$ E. of Gr.*)

Note: D and Z are negative; changes are in the algebraic sense.

April 11—There was a small sudden commencement at 10^h 40^m GMT, April 11. H increased 15 gammas in four minutes.

April 13-15—A sudden commencement occurred at 11^h 43^m GMT, April 13. H increased 30 gammas in four minutes. The storm continued until 02^h, April 15.

April 16—A large sudden commencement at 05^h 47^m 32^s GMT, April 16 was followed by a storm. Changes in D were: From 05^h 48^m to 06^h 20^m, $+54'$; from 06^h 20^m to 06^h 40^m, $-40'$; from 06^h 40^m to 07^h 15^m, oscillatory changes of about $\pm 12'$; from 07^h 15^m to 07^h 45^m, $-63'$; from 07^h 45^m to 08^h 40^m, oscillatory changes with a total change of $-41'$. Changes in H were: At 05^h 48^m, $+81$ gammas in five minutes, then small oscillations; from 06^h 00^m to 06^h 20^m, -209 gammas; from 06^h 20^m to 06^h 50^m, $+94$ gammas; from 06^h 50^m to 06^h 57^m, -146 gammas; from 06^h 57^m to 06^h 58^m, $+418$ gammas; from 06^h 58^m to 07^h 45^m, -580 gammas; from 07^h 45^m to 08^h 20^m, $+209$ gammas; from 08^h 20^m to 11^h 45^m, -141 gammas; from 11^h 45^m to 15^h 23^m, $+125$ gammas. The changes in Z were: From 05^h 48^m to 06^h 20^m, $+245$ gammas; from 06^h 20^m to 06^h 45^m, -384 gammas; from 06^h 45^m to 07^h 00^m, $+81$ gammas; from 07^h 00^m to 08^h 45^m, $+287$ gammas. The storm was of great intensity during the first three hours and lasted approximately ten hours. Bays developed in all elements about 21^h, April 16. Ranges: D, 100′; H, 580 gammas; Z, 594 gammas.

April 22—A small sudden commencement occurred at 11^h 59^m GMT, April 22, with a change in H of $+10$ gammas in five minutes.

April 25—There was a small sudden commencement at 01^h 15^m GMT, April 25, with a change in H of $+16$ gammas in five minutes.

May 11-13—A storm started at 15^h 54^m GMT, May 11, with a change in H of $+21$ gammas in three minutes. Changes in D were: From 18^h 00^m to 18^h 25^m, $-14'$; from 18^h 25^m to 18^h 45^m, $+15'$; from 19^h 05^m to 21^h 00^m, $-40'$; from 21^h 00^m to 22^h 27^m, $+21'$; from 22^h 27^m to 23^h 30^m, $-11'$; from 23^h 30^m May 11 to 00^h 15^m May 12, $+19'$. Changes in H were: From 15^h 58^m to 21^h 25^m, -251 gammas; from 21^h 25^m to 21^h 45^m, $+18$ gammas; from 21^h 45^m to 22^h 10^m, -104 gammas; from 22^h 10^m to 23^h 37^m, -26 gammas; from 23^h 37^m to 24^h 00^m, $+198$ gammas. Changes in Z were: From 16^h 15^m to 21^h 05^m, -328 gammas; from 21^h 05^m to 22^h 00^m, $+147$ gammas; from 22^h 00^m to 23^h 40^m, 49 gammas; from 23^h 40^m May 11 to 00^h 10^m May 12, $+213$ gammas. Ranges during this portion of the storm were: D, 43′; H, 299 gammas; Z, 277 gammas. Bays developed in all elements at about 23^h 45^m, May 12. D changed $+10'$ in fifteen minutes and $-12'$ in seven minutes. H changed $+41$ gammas in thirteen minutes and -21 gammas in twenty-two minutes. Z changed $+66$ gammas in twenty-five minutes and -25 gammas in fifteen minutes. The storm ended at 02^h, May 13.

June 7—There was a small sudden commencement at 22^h 03^m GMT, June 7, when H increased 26 gammas in four minutes.

June 12—There was a small sudden commencement at 17^h 56^m GMT, June 12, when H increased 21 gammas in three minutes.

Trigonometrical Survey Office, Capetown — A. Ogg, *Magnetic-Survey Adviser*

LIST OF RECENT PUBLICATIONS

By H. D. Harradon

A—Terrestrial and Cosmical Magnetism

Athens, Hydrographic Office. Magnetic chart of Greece. Hydrogr. Rev., Monaco, v. 15, No. 1, 1938 (115). [Reproduction of magnetic chart of Greece submitted with the "Report on terrestrial magnetic measurements in Greece," to the Edinburgh Assembly of the International Union of Geodesy and Geophysics, brought up to epoch January 1, 1938.]

Bartels, J. Potsdamer erdmagnetische Kennziffern. 1. Mitteilung. Zs. Geophysik, Braunschweig, Jahrg. 14, Heft 3/4, 1938 (68-78). [Die zeitlichen erdmagnetischen Variationen haben neuerdings für verschiedene Gebiete erhöhte Bedeutung gewonnen: drahtloser Nachrichtenverkehr und Ionosphärenforschung, Höhenstrahlung, Bodenforschung. Zur schnelleren Berichterstattung über den Charakter der Variationen wird deshalb eine zweiziffrige erdmagnetische Kennziffer K für dreistündige Abschnitte eingeführt; K_1 kennzeichnet die Intensität, K_2 die Form der Variationen. Die Definition von K wird mit dem Wesen anderer magnetischer Störungsmasse verglichen. Für Januar bis Mai wird K nach den Niemegker Registrierungen gegeben, ausserdem die Summe der 8 Ziffern K_1 für jeden Tag, nach 27tägigen Sonnen-Rotationen geordnet.]

Potsdamer erdmagnetische Kennziffern. 2. Mitteilung. Zs. Geophysik, Braunschweig, Jahrg. 14, Heft 5/6, 1938 (230-231).

Brandstetter, H., et J. Lagrula. Valeurs de l'inclinaison magnétique au Sahara et au Sudan. Paris, C.-R. Acad. sci., T. 206, No. 24, 1938 (1829-1830).

Chapman, S. Geomagnetism or terrestrial magnetism. Terr. Mag., Washington, D. C., v. 43, No. 3, 1938 (321).

Chramkov, E. G. Magnitye issledovaniia i izmereniia. Leningrad, Trd. Vses. Nauchno-Issled. Inst. Metrologii, No. 18, 1938 (199). 22 cm. [Magnetic researches and measurements. The articles in this collection are in Russian with brief French summaries. They are entered in this List of Recent Publications in their proper places according to authors.]

Coulomb, J., et G. Dugast. Sur les variations du magnétisme terrestre accompagnant les éruptions chromosphériques. Paris, C.-R. Acad. sci., T. 206, No. 21, 1938 (1582-1585).

De Bilt, Institut Météorologique Royal des Pays-Bas. Annuaire. Quatre-vingt-huitième année 1936. B. Magnétisme terrestre. (K. Nederlandsch Met. Inst. No. 98.) 's-Gravenhage, 1937 (viii+24). 34 cm.

Dijk, G. van. Magnetic character of the years 1890-1905. Terr. Mag., Washington, D. C., v. 43, No. 3, 1938 (245-246).

International selected magnetically quiet days and disturbed days, 1890-1894. Terr. Mag., Washington, D. C., v. 43, No. 3, 1938 (247-248).

Der magnetische Charakter der Jahre 1890-1905. Met. Zs., Braunschweig, Bd. 55, Heft 8, 1938 (302-304).

Dimmler. Die wöchentlichen magnetischen Beobachtungen in Jinsen, Taihoku, Otomari und Palau 1936. Ann. Hydrogr., Berlin, Jahrg. 66, Heft 7, 1938 (356-357).

Fedorov, E. Preliminary results of magnetic measurements at the "North Pole" station. Terr. Mag., Washington, D. C., v. 43, No. 3, 1938 (335-336).

Filchner, W. Magnetic work in Central Asia. London, Geog. J., v. 92, No. 1, 1938 (60-61).

Greenwich, Royal Observatory. Results of the magnetic and meteorological observations made at the Abinger magnetic station, Surrey, and the Royal Observatory, Greenwich, respectively in the year 1935, under the direction of H. Spencer Jones, Astronomer Royal. London, His Majesty's Stationery Office, 1936 (111 with 9 pls.). 30 cm.

Hess, V. F., A. Demmelmair, und R. Steinmaurer. Ueber Beziehungen zwischen erdmagnetischer Feldstärke und der kosmischen Strahlung. Wien, SitzBer. Ak. Wiss., Abt. IIa, Bd. 147, Heft 3/4, 1938 (89-100).

Hirayama, M. On the diurnal variation of the Earth's magnetic field. (First report.) Tokyo, J. Met. Soc., v. 16, No. 4, 1938 (142-159, 43-44). [Japanese text with English abstract.]

Jackson, W. E. W. Record of observations at the magnetic observatories Agincourt and Meanook, 1932-1933. Ottawa, Dept. Transport, Air Services Branch, Div. Met. Services, 1938, 138 pp. 32 cm.

Janovsky, B. M. Le magnétomètre transportable pour la détermination de la perméabilité magnétique des roches. Leningrad, Trd. Vses. Nauchno-Issled. Inst. Metrologii, No. 18, 1938 (95-107). [Texte russe avec résumé français.]

Sur les méthodes des mesures magnétiques absolues. Leningrad, Trd. Vses, Nauchno-Issled. Inst. Metrologii, No. 18, 1938 (154-167). [Texte russe avec résumé français.]

Magnétographes. Leningrad, Trd. Vses. Nauchno-Issled. Inst. Metrologii, No. 18, 1938 (167-184). [Texte russe avec résumé français.]

Nouveau système magnétique pour les instruments de mesure à cadre mobile. Leningrad, Trd. Vses. Nauchno-Issled. Inst. Metrologii, No. 18, 1938 (184-189). [Texte russe avec résumé français.]

Koenigsberger, J. G. Stabilität der magnetischen Thermoremanenz in Tongegenständen und Gesteinen bei Bestimmungen des magnetischen Erdfeldes in der Vergangenheit. Beitr. Geophysik, Bd. 53, Heft 4, 1938 (345-351).

Natural residual magnetism of eruptive rocks, Part II. Terr. Mag., Washington, D. C., v. 43, No. 3, 1938 (299-320).

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Matuoka, Y. On the 14-day recurrences of terrestrial magnetic activities. Tokyo, J. Met. Soc., v. 16, No. 3, 1938 [117-119, (10)-(11)]. [Japanese text with English abstract.]

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Minakami, T. Magnetic surveys of volcano Asama. Bull. Earthquake Res. Inst., Imp. Univ., Tokyo, v. 16, Pt. 1, 1938 (100-116).

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Nagata, T. Magnetic anomalies and the corresponding subterranean structure. Tokyo, Proc. Imp. Acad., v. 14, No. 5, 1938 (176-181).

A dip variometer. Bull. Earthquake Res. Inst., Imp. Univ., Tokyo, v. 15, Pt. 1, 1937 (185-192 with 2 pls.).

Magnetic anomalies around volcanic craters. Bull. Earthquake Res. Inst., Imp. Univ., Tokyo, v. 16, Pt. 2, 1938 (288-299).

Principal Magnetic Storms. April to June, 1938. Terr. Mag., Washington, D. C., v. 43, No. 3, 1938 (337-341).

Procopiu, St., N. Calinicenco, et G. Vasiliu. Mesures magnétiques en Roumanie en 1937. Extrait, C.-R. Acad. sci. Roumanie, T. 2, No. 3, 1938 (246-255).

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SPIRIDOVITCH, N. I. Propriétés magnétiques et constituantes magnétiques des roches. Leningrad, Trd. Vses. Nauchno-Issled. Inst. Metrologii, No. 18, 1938 (107-154). [Texte russe avec résumé français.]

STEINKE, E. G., UND A. SITTKUS. Ultrastrahlung und magnetische Stürme im Januar, April und Mai 1938. Naturw., Berlin, Jahrg. 26, Heft 28, 1938 (461-462).

STENZ, E. Remarques sur les observations de la composante verticale du magnétisme terrestre à Swider. Beitr. Geophysik, Bd. 53, Heft 4, 1938 (368-370).

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B—Terrestrial and Cosmical Electricity

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Healey, R. H. The effect of a thunderstorm on the upper atmosphere. A. W. A. Tech. Rev., Sydney, v. 3, No. 4, 1938 (215-227). [The effect of a thunderstorm on the ionization-density of the E-layer is investigated, using the method given by Bailey in 1937 for the calculation of the motion of electrons in gases under the

action of electric and magnetic fields. It is estimated that during the day less than one per cent of the flashes will cause a notable increase in the ionization, but that at night this proportion is considerably greater; and that if there always exists in the ionosphere a constant electric field of the order of 0.5v/m the increase will often be very marked. The effect of such changes in the ionization-density on the propagation of radio waves is then briefly considered.]

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Rose, D. C. The variation of the electrical conductivity of the atmosphere with height. Can. J. Res., Ottawa, v. 16, 1938 (107-130). [The conductivity and potential-gradient were measured during seven aeroplane flights near the ground-level and up to 16,000 feet during the autumn and winter of 1936-37. The conductivity-measurements appear satisfactory and constitute a valuable addition to available data. The author regards the potential-gradient results as affected by charges on the aeroplane etc. The conductivity was found to increase rapidly with height in a manner in general agreement with data of other observers. Positive and negative conductivities were found to be equal, within the experimental error, at heights between about 1,000 and 10,000 feet. At higher altitudes the negative conductivity was greater than the positive. The presence of clouds and frontal discontinuities usually caused a reduction in conductivity.]

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Vorgänge und Zustände in der Nordlichtregion. Geofys. Pub., Oslo, v. 12, No. 5, 1938 (23 with 2 pls.).

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C—Miscellaneous

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